THE FRONTISPIECE.

Tycho Brahe measuring the Altitude of the Sun in 1587.

ABRIDGED EXPLANATION.
Translated from the Latin by the Rev. C. R. Leetham, M.A., and B. F. Foley.

I had made a very large Quadrant (here represented by BDEC) called Tychonic or Mural—from the wall to which it was fixed. It was cast from solid brass and specially lightened, being five fingers broad, two fingers thick, and sufficiently long in circumference for a radius or semi-diameter of almost fifty Cubits. Consequently, the degrees are so large that each minute is subdivided into six parts, and divisions consisting of ten seconds each are clearly seen, so that in the half of such a division five seconds may obviously be reckoned.

This quadrant is fixed to a wall facing due South, and is held by strong screws so that it cannot be violently wrenched out of position, the other wall, which is at right-angles to the former and faces due East and West, has high up on it at the centre of the Quadrant a cylinder of brass, gilded to preserve it from being attacked by the atmosphere.

When the Sun is shining collomation is secured on either side of the cylinder by means of the sights D or E. If the Altitude is wanted, the Observer (shown by the letter F) performs his task by lining up the slits in the sights with the corresponding parts of the cylinder A. He tells the other student (G) seated at a table with a light, the number of the Altitude, so that he can enter it in the Observation Book. But in order to make certain of the time of observation and the exact moment of the crossing of the meridian, a third person (H) watches the clocks (I and K), and when the observer at F gives the signal, the exact time is noted in the book by the person seated at G. The clocks which I have mentioned are of such a kind as to indicate with precision not only each minute of the hour, but also, as far as possible, the tiny seconds, and to emulate the evenness of the celestial revolution.

All the pictures inside the circumference of the Quadrant are added merely for the sake of ornament and to avoid the waste of the intervening space. Over my head, at the spot marked X, a brass gilt globe is shown which has little wheels inside it skilfully arranged so that the globe revolves of its own accord and imitates the diurnal motion. At the same time it shows the courses of the Sun and Moon, and the waxing and waning of the Moon with its faces and illuminations.

Above the globe there is represented a portion of my Library (V). At Y and Z hang two portraits solidly done in circular frames, one of that most Serene and Powerful King of the Danes, Frederick II, of most excellent memory; the other of the most Serene Queen Sophia, his most illustrious spouse, both of whom have always taken a Royal and indulgent interest in me and my studies.

The things seen in the inner picture, by the numbers 1, 2, 3 and 4, are drawings of some of my instruments. Then, on the floor below, you see a Study in which there are two tables (5 and 8), at which my astronomy pupils usually sit whilst they are making their calculations and the like. In between these tables and behind the column raised in the middle of the circular Study is seen the big brass globe (6 and 7), six feet in diameter, which I shall demonstrate and explain in due course. Finally, underneath all this, you see my Chemical Laboratory, which was built entirely underground and in which I had provided sixteen fire furnaces of various kinds and shapes. Last of all, at my feet, by the number 12, lies one of my hounds, very faithful and sagacious.

There you have a brief exposition of the whole picture (in so far as it could be drawn in so small a form), which was drawn for me by three different excellent artists. Tobias Gemperlinus, the painter of Augsberg, drew my portrait; my architect, John of Embda Stenivichel, drew the architectural part and the things contained therein. The drawings at the top of the picture, which show countries and mountains with the Sun seen at its setting, were added by John of Antwerp, the Regius painter of Coronaburg. Each of these three artists excelled all others in his own work. Finally, above this again, by R and S, there is, as you see, an inscription to go with the portrait and the whole picture.

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FRONTISPIECE.

Tycho Brahe measuring the
Altitude of the Sun in 1587.

Preceding pages).

ASTRONOMICAL AIR NAVIGATION

A Comprehensive Handbook embodying the Latest Principles for Practical Navigators, Instructors and Students

By
SQUADRON-LEADER
RONALD HADINGHAM, R.A.F.O.

WITH A FOREWORD BY
AIR-COMMODORE P. E. MAITLAND, M.V.O., A.F.C.

SECOND EDITION
Revised and Enlarged

FOREWORD

BY

AIR-COMMODORE P. E. MAITLAND, M.V.O., A.F.C.

My excuse for writing these few words is that the author has served under me for the last few years, and that I myself have been closely connected with air navigation since the early days of 1915— when the aircraft compass was still a flat card, marine-type compass mounted on a horse-hair pad " to damp vibration."

During most of this time there has been a great need for practical books on air navigation, and the rapid progress of navigation during the war, coupled with the necessary limitations imposed by the need for secrecy, have made this want greater than ever.

The author has had recent experience both of practical navigation and of lecturing on the subject to Air Crews, and I feel sure that his book will prove of practical value to those about to study air navigation, and also to instructors requiring a handbook to supplement their own knowledge.

PREFACE

This book has been written for practical navigators. Its purpose is to provide a complete course in Astro-Navigation, with only essential references to the mathematical and theoretical aspect. I feel sure that few air navigators will have time to study the less practical methods by which the technique may be applied, some of which involve plane or spherical trigonometry, and are of interest only to a few specialists.

A certain knowledge of basic principles is, of course, necessary as a foundation, if the practical work is to be fully understood. Such principles have, therefore, been included, together with a certain amount of elementary astronomy which will help the navigator to appreciate the nature of the heavenly bodies and their movements.

The photographs of Royal Air Force material and extracts from the Air Almanac and Astronomical Navigation Tables have been reproduced by permission of H.M. Stationery Office, to whom acknowledgment is hereby given.

My thanks are due to Professor H. Plaskett for the information on Acceleration Errors that he has kindly provided, as well as to many friends in the Royal Air Force who, having shared my experiences, encouraged the writing of this book.

R.H.

R.A.F., Egginton Hall.

PREFACE TO THE SECOND EDITION

I am fortunate in being able to include in this edition two instruments which have been of immense value to air navigation during the war, and which will undoubtedly add greatly to the safety of every long-distance aircraft of the future :

The Mark IXA Sextant has overcome the problems of sight taking during the unsteady conditions of flight, and astro position lines are now possible with errors averaging two miles and not exceeding five miles.

The Astrograph has removed the last trace of mathematics from the process of sight reduction, and the time spent between sighting the heavenly bodies and obtaining the fix has been cut down to a fraction of its former amount.

Chapter Three has been completely rewritten and enlarged, to cover the all-important subject of Star Identification and Star Movements in greater detail.

I wish to thank Sir Harold Spencer Jones, F.R.S., The Astronomer Royal, who very kindly made suggestions for the improvement of Chapter Seven, which have now been incorporated.

<div align="right">R.H.</div>

R.A.F., C.M.F.

CONTENTS

CONTENTS—*continued.*

" FOR OF MERIDIANS, AND PARALLELS,
   MAN HATH WEAV'D OUT A NET, AND THIS NET THROWNE
   UPON THE HEAVENS, AND NOW THEY ARE HIS OWNE.
   LOTH TO GOE UP THE HILL, OR LABOUR THUS
   TO GO TO HEAVEN, WE MAKE HEAVEN COME TO US."

                                        John Donne, 1611.

ASTRONOMICAL AIR NAVIGATION.

Chapter One.

PRELIMINARY STUDY.

THE CELESTIAL SPHERE.

    1. Although the Heavenly Bodies are scattered through space at different distances from the earth, it is convenient to consider them as lying on the surface of a vast sphere, having the earth at its centre. Accurate measurements may be made on the face of this sphere by reference to meridians, parallels and other circles, just as on the earth. These are known as Circles of Reference, and the imaginary sphere surrounding the earth is called the Celestial Sphere.

THE CELESTIAL SPHERE.
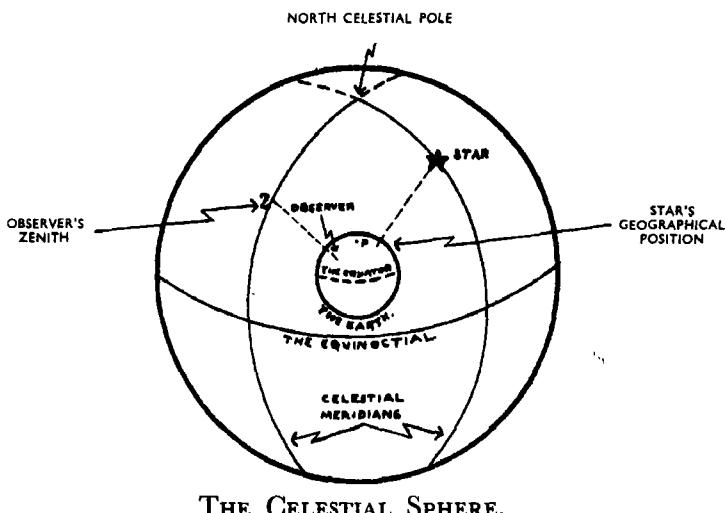
Fig. 1.

THE CELESTIAL POLES.

    2. These are imaginary points on the Celestial Sphere lying immediately over the north and south Geographic Poles of the earth. A line from the centre of the earth through the Geographic Poles, if produced, would pass through the Celestial Poles.

THE EQUINOCTIAL.

3. The plane of the earth's equator may be projected outwards on to the Celestial Sphere to form a great circle known as the Equinoctial. A line joining the north and south Celestial Poles would therefore be perpendicular to the plane of the Equinoctial.

CELESTIAL MERIDIANS.

4. Celestial Meridians are semi-great circles (half of great circles) on the Celestial Sphere joining the Celestial Poles. They may be likened to meridians drawn on the surface of the earth from pole to pole.

ZENITH.

5. The observer's Zenith is that point on the Celestial Sphere which lies immediately over his head at any given moment. A line from the centre of the earth through the observer's position, if produced, would meet the Celestial Sphere at his Zenith.
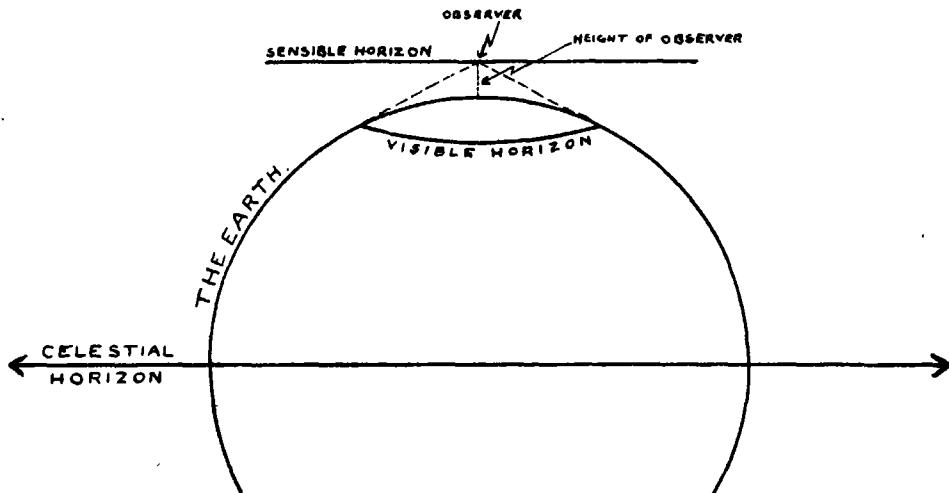
Fig. 2.

Similarly, the point on the earth that lies immediately beneath any heavenly body is called its Geographical Position, and is located by a line from the body to the centre of the earth.

HORIZON (see Fig. 2).

    6 (*a*).   The Visible Horizon.

           The Horizon formed by the extreme limits of the observer's visibility. It will be a small circle on the earth with centre the observer's geographical position.

    (*b*).   The Sensible Horizon.

           A plane passing through the observer's eye-level and at right angles to a line joining his position to the centre of the earth. This would be a plane formed by any kind of bubble levelling device, such as a spirit level.

    (*c*).   The Celestial Horizon.

           A great circle on the celestial sphere whose plane is perpendicular to a line from the observer's zenith to the centre of the earth. It will be seen that the celestial horizon is parallel to, but not coincident with the sensible horizon.

Fixing Position on the Celestial Sphere.

    7 (*a*).   The position of any heavenly body may be defined precisely in terms of its Hour Angle and Declination.

G.H.A.*=300°.
L.H.A.*=120°.
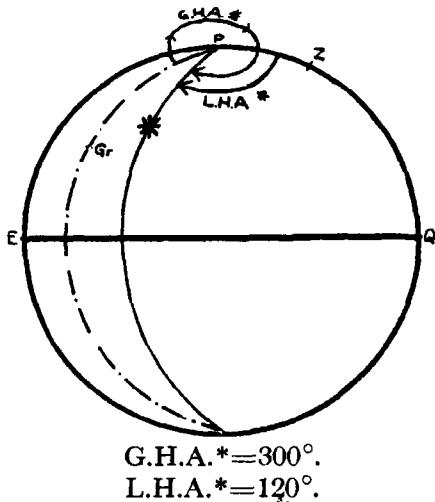
Fig. 3.

HOUR ANGLE.

An Hour Angle is the angle at the celestial pole between celestial meridians, and is *always* measured in a westerly direction.

Thus : The Greenwich Hour Angle (abbreviated G.H.A.) of SIRIUS is the number of degrees that the Meridian* of Sirius lies west of the Greenwich Meridian. (Fig. 3.)

L.H.A., or Local Hour Angle, is an hour angle measured westwards from the observer's meridian.

S.H.A., or Sidereal Hour Angle, is an hour angle measured westwards from the Meridian of the First Point of Aries. (Chapter 2, para. 16-18.)
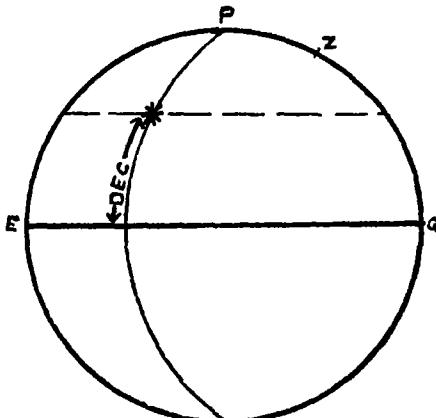
DECLINATION=50°N.

Fig. 4.

DECLINATION.

7 (*b*). The Declination of a heavenly body is the smaller arc of the meridian cut off by the equinoctial and the body, and is named north or south according to whether the body is north or south of the equinoctial. (Fig. 4.)

The measurement of Hour Angle and Declination may be likened to the longitude and latitude system of reference on the earth's surface.

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* The word " celestial " is frequently omitted when referring to celestial meridians in cases where there is no probability of confusion.
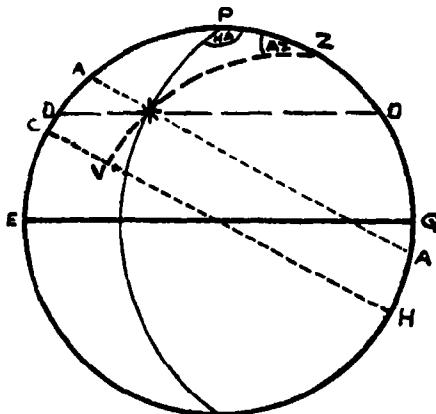
L.H.A.*=120°.　　DEC.=50°N.
ALT.= 30°.　　　AZ.=N.45°W. (315°T).

DD=CIRCLE OF DECLINATION.
AA=CIRCLE OF ALTITUDE.
CH=CELESTIAL HORIZON.
VZ=VERTICAL CIRCLE.

Fig. 5.

AZIMUTH

8.　The Azimuth Angle of a heavenly body is measured at the observer's zenith (as opposed to hour angle, measured at the pole), and is usually called east or west of the nearer pole.

Thus, SIRIUS lying north-west of the observer would have an azimuth of N.45°W. When no cardinal points are specified, then the azimuth is assumed to be north and east in the usual way. Thus SIRIUS north-west of the observer would be 315°T. (See Fig. 5.)

ALTITUDE.

9.　The altitude of a heavenly body is its angular measure, from 0 to 90 degrees above the sensible (or celestial) horizon. Or, in other words, the smaller arc of the vertical circle passing through the body, cut off by the celestial horizon and the body.

B

(A vertical circle is any great circle passing through the zenith and thus meeting the celestial horizon at right angles. See Fig. 5.)

THE POSITION LINE.

10. A Position Line is a line on the surface of the earth which passes through all possible positions of the observer at the time of the observation.

It is considered to be straight for all practical purposes in astro work. (See para. 11 (*b*) of this Chapter.)

The Circle of Position.

11 (*a*). The following two special cases for the position of the observer will immediately show the meaning and significance of the Circle of Position.
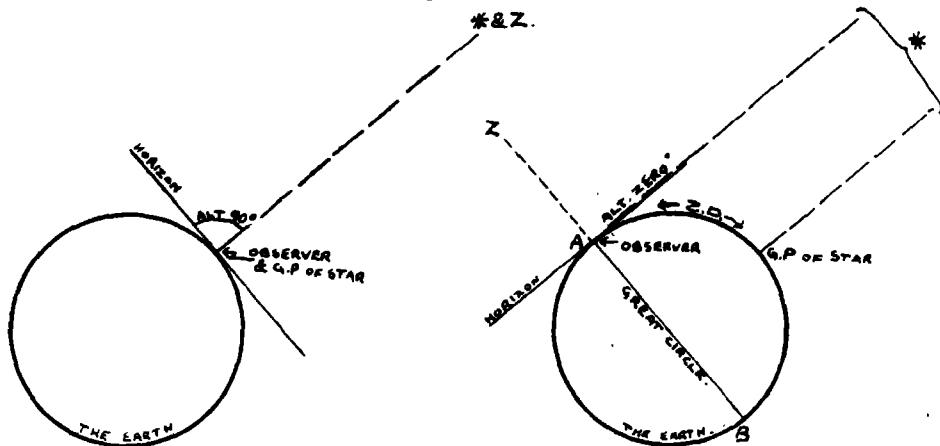
Case I.—Observer at G.P. of Star.
∴ Alt.=90°, Z.D.=0°.

Case II.—Observer Anywhere on Great Circle 90° from G.P. of Star.
∴ Alt.=0°, Z.D.=90°.

Fig. 6.   Fig. 7.

CASE I. (Fig. 6.)

Observer located at the Geographical Position of the heavenly body. The body will be in the observer's zenith. ∴ *Altitude* = 90°.

CASE II. (Fig. 7.)

Observer located 90° from Geographical Position of body. The body will lie on the sensible horizon. ∴ *Altitude* = 0°.

From these two important facts, the following conclusions may be drawn :

1.   There is only one point on the surface of the earth at any given moment from which the altitude of a heavenly body can be 90°, viz., its Geographical Position.

2.   There are many positions from which the altitude is 0°, but they all lie on a great circle (AB) whose plane is at right angles to the Geographical Position of the body.

3.   Similarly, small circles may be drawn through all points from which the body will have the same given altitude (45°, for example), and such small circles will all be concentric about the Geographical Position.

4.   The radius of such a circle is called the ZENITH DISTANCE, and from cases 1 and 2 it will be seen that its value is always 90°—altitude. In case 1, ZENITH DISTANCE (abbreviated Z.D.) is zero, since the circle of position is a point, having nil radius.   In case 2, the Z.D. is 90°, since the circle is a great circle.   Thus, *Zenith Distance* = " *Co-Alt.*"

11 (*b*).   A circle with centre the Geographical Position, and radius the Zenith Distance, is called the Circle of Position, and although a curve, it is drawn as a straight line, since its radius is so enormous that the small section required that runs across the map is only slightly curved.
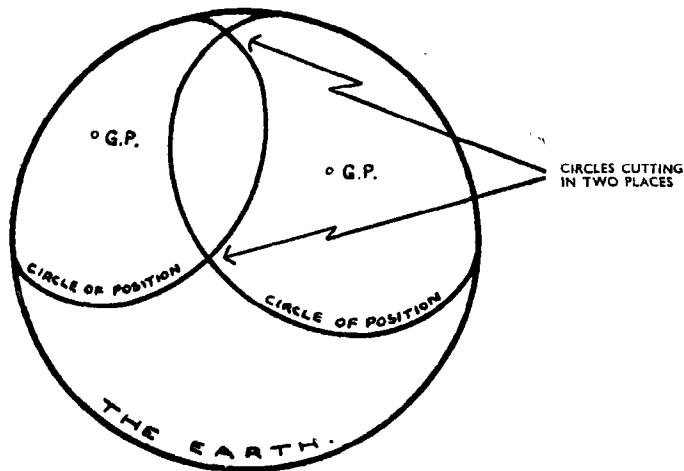
Fig. 8.

So far, however, only a single position line has been considered, which is of very limited value. To fix the observer's position precisely a second heavenly body must be observed simultaneously (or a specified number of minutes later) to obtain a second circle of position that will cut the first in two places (see Fig. 8). Owing to their distance apart, no confusion can arise in selecting the correct intersection, and this point must be the observer's position, since it is the only point that satisfies the altitudes of both heavenly bodies with relation to their geographical positions at the time of observation.

12 (*a*). To sum up, firstly, the GEOGRAPHICAL POSITION of the body must be found. To do this, the time and date of observation must be known in order to obtain the HOUR ANGLE and DECLINATION.

Secondly, the ALTITUDE must be observed at the above time to give the ZENITH DISTANCE (the radius of the circle from the G.P.), and thus the POSITION LINE.

12 (*b*). The following information is therefore required for calculating the sight :

1. Date and time of observation.

2. Name of body observed (and its celestial location).

3. Altitude of body at the above time ($\pm$ any sextant, or other errors).

4. A very approximate D.R. position.

Time.

13. It is most important at this stage to have a clear conception of Time, which is one of the primary factors to be considered in all astro problems.

A Solar Day is the length of time between two successive meridian transits of the sun. That is to say, it is the time that the earth takes to revolve once on its axis, bringing the sun back to the same apparent position in the sky.

At first sight this would always appear to be 360 degrees of the earth's rotation, but because the earth is also moving on a path around the sun, the period varies slightly in length according to the earth's position in orbit. This is discussed more fully in Chapter 5.

We naturally wish to " pace " the days by the rising and setting of the sun, which conveniently divides the period into day and night, but it would be very trying if the period varied slightly in length—as indeed it would do if clocks were set according to the sun's daily position. The simple solution adopted is to take the mean length of all the solar days in a year, and call this measure a Mean Solar Day, subdividing it into 24 hours of mean time. The meridian of Greenwich was agreed upon as a suitable datum for measuring this time, and thus it comes to be known as Greenwich Mean Time, abbreviated G.M.T. The time that is kept on the clocks in everyday life is Zone Time, which is simply G.M.T. + or − a correction for the distance the observer is situated east or west of the Greenwich Meridian. For convenience, this correction, rather than being applied gradually with change in longitude, is applied at intervals of 15°, or one hour. The sections so formed are called Zones, there being 24 such Zones dividing the earth into 24 hours of Zone Time, similar to the slices in an orange.

Zone Time in the Greenwich Zone (Zone 0) will thus be the same as G.M.T., since there is no longitudinal difference. Each zone to the east and west of the Greenwich Zone will be an hour different from it, and so on up to 180° of longitude from Greenwich, which will be different by 12 hours.

The similarity between time and arc (angular measure) should be noted. 360° of arc equals 24 hours of time, and from this all angles may be measured in terms of either quantity, or freely converted from one measure to the other.

Time, from the astro-navigator's viewpoint, is always measured in units of G.M.T., no matter where he may be situated on the earth. The astronomical watch will invariably be set to read G.M.T., and thus it may frequently differ considerably from the Zone Time on civil clocks, depending on the longitudinal distance from Greenwich.

Summer Time is an arbitrary factor that is superimposed on the Zone Time for practical convenience, and one or two hours must be subtracted when it is in force if the true Zone Time is required. It is not correct to put summer time on an astro watch, but this is often done for the convenience of the user, who should always remember to subtract one or two hours as necessary to obtain the Zone Time or G.M.T.

It is an unfortunate fact that navigational watches are graduated with a twelve-hour face, rather than twenty-four hours. If the longitude of the observer is sufficient to make the Zone Time differ considerably from the Greenwich Mean Time, then it may not be clear at first whether the G.M.T. is 03.00 hours or 15.00 hours, for example. The method of checking is to apply longitude to the Zone Time, which will give G.M.T. to the nearest half-hour. By inspection the G.M.T. is then either accepted as 03.00 hours or 12 hours is added to make it 15.00 hours, according to the approximate G.M.T. obtained from the Zone Time. Care must be taken to watch for change of date between Zone Time and Greenwich Mean Time. If, when converting from one to the other, one passes from 23.00 hours to 00.00 hours, or vice versa, then the date must be increased by a day, or decreased respectively.

For example : if an observer in longitude 45° West (3 hours) observes his Zone Time to be 22.30 hours on November 15th, then the G.M.T. at that moment will be 01.30 hours on November 16th.

Local Mean Time (L.M.T.) is G.M.T. $\pm$ the exact longitude of the observer, and will therefore always be within half an hour of the Zone Time. L.M.T. is a precise value that is of use to the astro-navigator, whereas Zone Time, being the mean of each 15 degrees of longitude, is only of use as a check on the G.M.T. prior to commencing the sight calculations.

In all problems of converting from one unit of time to another the following rule is invariable, *provided* that the word " Greenwich " is always used :

"Longitude West, Greenwich Time Best."

"Longitude East, Greenwich Time Least."

Thus, for an observer in 45°W, his G.M.T. must be " best," or greater than his Zone Time or L.M.T. For an observer in 45°E, his G.M.T. must be " least," or smaller than his Zone Time or L.M.T. This rule is of great importance, and it is frequently involved in astro problems. It is far preferable to the practice of giving zones plus or minus signs which can be very misleading under certain circumstances.

WATCH ERROR.

14. No watch can be expected to keep perfectly accurate time over a period of days, but the loss or gain of a good watch should be a consistent quantity that can be applied as a known error to the watch reading.

It is usual to set the astro watch by the Greenwich Time signal on the wireless, the sixth " pip " marking the hour exactly. On each successive day, however, the watch is not re-set to agree precisely with Greenwich once again. Instead, a note is made of the watch reading at the sixth " pip," say, 7 seconds fast. On the following day, at the same time, the watch should be 14 seconds fast, and so on. Thus the true G.M.T. should be known even if the time signal is missed for a day or two. This daily change is known as the " Rate " of the watch, and the Rate × the number of days elapsed since setting will give the plus or minus watch error to be applied. It is a less accurate method to attempt to re-set the watch to nil error each day, in addition to which extra wear and tear is involved in constant readjustment of the mechanism.

Corrections to Sextant Readings.

Several factors must be considered before a sextant reading may be used in the calculation of an astro sight.

SEXTANT CORRECTION (Abbreviated S.C.).

15. Every sextant has certain individual characteristics that cannot be avoided in manufacture, and which may produce a small error in the altitude reading. Wear and tear or heavy shocks may also introduce new errors into the sextant which are not always apparent immediately they exist, therefore extreme care in handling the sextant at all times will be well repaid by its reliability.

The only satisfactory method of calibrating the values of sextant correction is by a series of actual observations taken on the ground with the sextant supported to give the most accurate possible readings. A series of observations should be made, consisting of about a dozen separate sights at each ten degrees of altitude between 10° and 80°. The error of each sight, when plotted, on either side of the true position is then measured, and given a plus or minus sign according to whether the altitude is greater or smaller than that required to give nil error. To convert the error to a correction, change the sign and plot a correction graph as in Fig. 9.

Included in this value of Sextant Correction will be the observer's Personal Error.
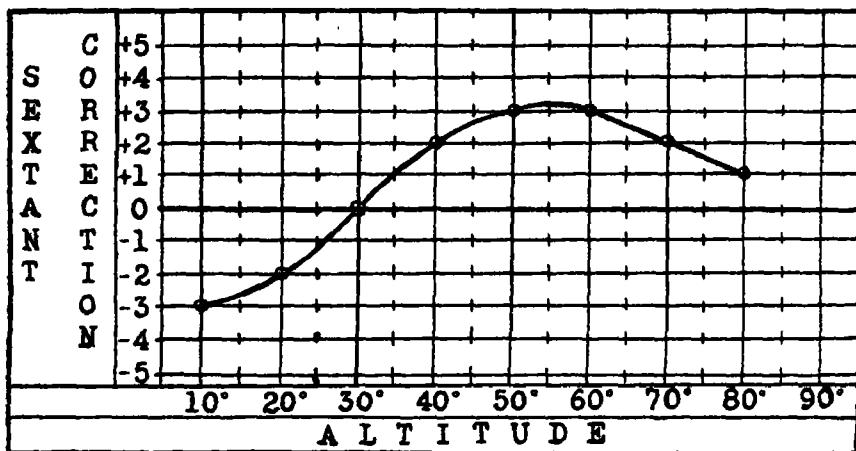
Fig. 9.

PERSONAL ERROR.

16. No two people, when setting a heavenly body exactly on a bubble, will get the same answer. The usual tendency is to place the body a little above or below the bubble by a fractional amount, even though the observer is unaware of the fact.

This " Personal Error " has been investigated by a number of scientists with a view to discovering its cause and a practical method by which it may be eliminated. The value of Personal Error for any individual is difficult to determine accurately, since it cannot easily be divorced from other sextant errors. Since it is always present when calibrating Sextant Correction, it is automatically allowed for and need not concern the observer provided he has calibrated his sextant himself.

An excellent method of reducing personal errors to a minimum is by varying the direction from which the heavenly body is brought into coincidence with the sextant bubble. When taking a run of six shots for an averaged sight, the sun may be brought down to the bubble for the first three shots, then for the second three the image of the sun is moved below the bubble and brought *up* into coincidence with it. This procedure will be better understood after studying the chapters that follow.

REFRACTION (Abbr. Rf.).

17. It will be remembered that " a ray of Light, in passing from a rarer to a denser medium is refracted towards the normal of the plane of separation between the mediums."

This phenomenon is of great importance to any astronomical work, since light coming from all the heavenly bodies passes from Space (the rarer medium) to the earth's Atmosphere (the denser medium), and is therefore subject to refraction.

In Fig. 10, the light from a star X will reach the observer on a path indicated by the heavy line. The final direction of this line is such that the star appears to be higher in the sky than it really is. This illusion is shown by producing the final direction backwards along a dotted line to give the " apparent " star at X_1. The intermittent line represents the star's true altitude, the dotted line shows its apparent altitude. The angle X O X_1
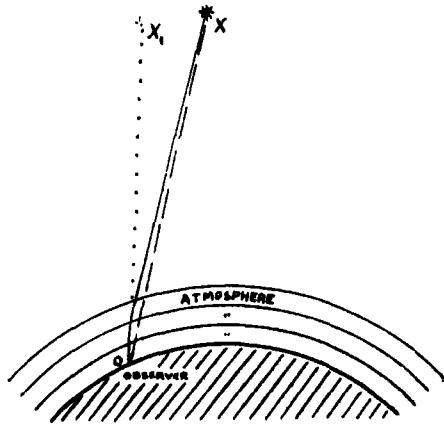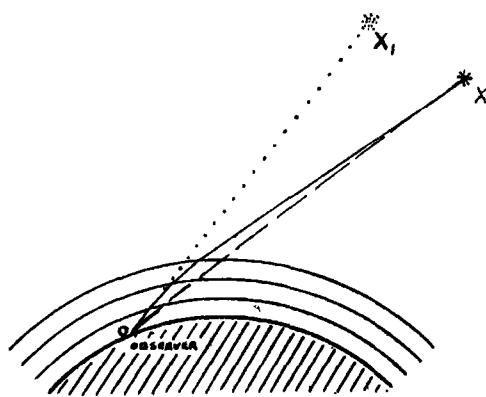
Fig. 10. Fig. 11.

is the value of refraction, and since the altitude of the apparent star is greater, the VALUE OF REFRACTION IS ALWAYS NEGATIVE, and must be subtracted from the observed altitude.

By comparing the two figures, it will be seen that the value of refraction increases with decrease in altitude ; the light has to traverse a greater thickness of the earth's atmosphere owing to the oblique angle at which it

enters. Sights should never be taken below altitude 12°, because refraction becomes large and frequently variable.

Refraction will also decrease slightly with increase in height, since the effect of increasing the observer's height is to lessen the amount of atmosphere lying between himself and the star.

Refraction varies within very fine limits on account of changes in the atmosphere, principally water vapour. Fortunately this variation is negligible in the degree of accuracy required, and a mean table for refraction is given on the back of the rear cover of the Air Almanac (A.P. 1602), and also in the back pages of the Astronomical Navigation Tables (A.P. 1618).*
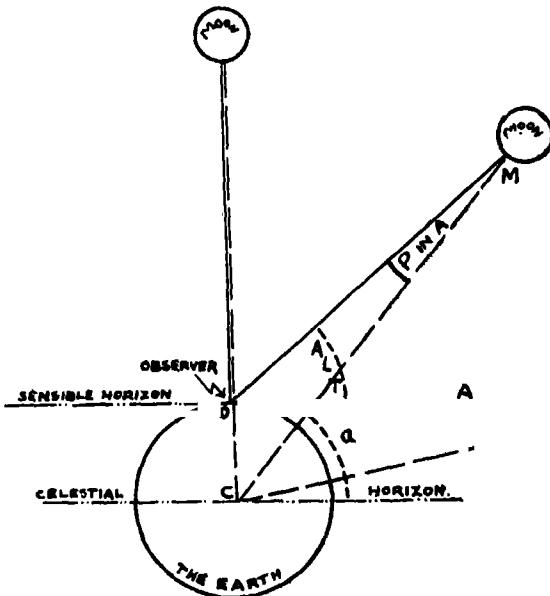
Fig. 12.

PARALLAX IN ALTITUDE (Abbr. P. in A.). MOON ONLY.

18. The limits of accuracy of astro-navigation are such that allowance for parallax of the heavenly bodies is unnecessary on account of their great distance from the earth.

* The value of refraction has been incorporated in the tabulations of the Astronomical Navigation Tables, and, therefore, MUST NOT be applied when working with these publications.

The Moon is one important exception, however, which is relatively close to the earth.

In Fig. 12, there is a noticeable difference in the altitude of the moon measured from the centre of the earth (a), and measured from an observer at O (angle MOA). The angle OMC is the value of P. in A., and it will be seen that the altitude from O is less than from the centre of the earth. Therefore, the VALUE OF P. in A. IS ALWAYS POSITIVE, and must be added to the observed altitude.

The three cases in the figure show how the P. in A. increases with decrease in altitude, being nil when the moon is in the Zenith, and a maximum when the moon is on the horizon. This maximum value is known as the Horizontal Parallax.

Whereas refraction was a constant that could be tabulated permanently, P. in A. must be given for each successive day, since the moon's distance from the earth varies, and thus the angle subtended will vary accordingly.

P. in A. will be found tabulated for each day on the Moon data pages of the Air Almanac. (See Appendix A, Table 2.)

SUMMARY.

19. (a). Always use the same sextant. This should be calibrated from your own sights, taken under ideal conditions.

(b). Sextant correction includes the Personal Error of the person who made the observations ; therefore the value will not necessarily be correct for other people. .

(c). All astronomical observations are subject to refraction, the amount of which increases with decrease in altitude. Minimum permissible sighting altitude, 12 degrees.

(d). A mean refraction value has been incorporated in the tabulations of the A.N. Tables. Do not, therefore, apply any correction when using these tables.

(e). Parallax error is only appreciable in the case of the moon. P. in A. error must invariably be added to observed altitudes of the moon.

CHAPTER TWO.

PROCEDURE.

1. " Working out a sight " is a process which the navigator must carry out at speed, and frequently under trying circumstances. For this reason he should practise use of the methods that follow in this chapter until each step becomes quite automatic. Approximately twenty observations should be made and calculated on the ground, to familiarise the navigator with the procedure before he attempts to obtain results in the air.

2. It has been shown that by observing the altitude of a heavenly body, and drawing on the earth a circle with centre the Geographical Position of the body, and radius 90°—Altitude, this circle may be used as a position line and must pass through the point from which the observation was made.

This may be simplified and reduced to a more practical form. It is known from the approximate D.R. Position that nine-tenths of this vast circle on the earth is unnecessary since it is far from the observer's position, in England, for example, and in addition the fact that he is working on a map rather than on a spherical globe would not permit more than a small part of the circle to be drawn.

It would be simple, however, to draw in a line of azimuth between the approximate D.R. Position and the Geographical Position of the body, and mark along it from the G.P. a distance equal to 90°—Altitude, or the Zenith Distance.

3. Thus the necessary part of the circle of position is selected, but the problem remains of measuring the Zenith Distance from the G.P. of the body, which will be a point off the map, and anything from 1,800 miles distant. The solution to this problem is known as the Marcq St. Hilaire method of plotting the position line, being as follows.

4. A Position is Assumed, measured in latitude and longitude, which is estimated as being within some sixty miles of the observer's unknown position. Tables are consulted to discover the altitude and azimuth of the

heavenly body had it been observed from this assumed position at the moment when the actual sight was made.

Now if, in fact, the observer was at this assumed position, then his observed Sextant Altitude would be the same as that calculated by tables. The difference between the observed altitude and the calculated altitude will be proportional to the distance, measured along the line of azimuth between the circle of position that passes through the observer and that which passes through the assumed position.

Thus, by plotting the assumed position, laying off the azimuth line through it, and marking along it a distance equal to the difference between the observed and calculated altitude, the position line may be drawn in—really part of the huge circle of position—upon which the observer's true position must lie.

5.   This difference between the two altitudes is called the INTERCEPT, and is measured in minutes of latitude (nautical miles).   Where the observed altitude is of a less value than the calculated altitude, then the observer must be further from the G.P. of the body than the assumed position.   (Chap. 1, para. 11 (a)).   This would be a case of Intercept " Away."   Where the observed altitude is of a greater value than the calculated altitude, the observer must be closer to the G.P. than the assumed position, and the Intercept would be called " Towards."

6.   The first of the following examples has been laid out in full detail to explain the application of the above theory ;   basically all other sights, whether star, moon or planet, are calculated in a similar manner, allowance being made for small differences that are peculiar to each type of heavenly body.

The following abbreviations have been used throughout :

Sext. Alt.   Observed Altitude before application of Sextant Corrections.

Obs. Alt.   Observed Altitude fully corrected.

Calc. Alt.   Altitude from the assumed position (at the time of the Obs. Alt.).

S.C.   Sextant Correction.

Rf.   Atmospheric Refraction.

M.W.R.   Mean Watch Reading (Mean of the starting and finishing times of the observation).

P. in A.   Parallax in Altitude.

Az.   Azimuth (of the heavenly body from the assumed position).

Int.   Intercept.

Dec.   Declination (of the heavenly body).

EXAMPLE—Sun Sight.

7.   On October 1st, a navigator, whose approximate D.R. Position is 51°06'N, 05°10'W, observes the Mean Altitude of the SUN to be 31°29', his G.M.T. watch reading 10 hrs. 25 mins. 30 secs.

The watch is 7 seconds slow, and the Sextant Correction at this altitude is + 3'.

It is required to plot the position line passing through the observer.

8.   The right-hand page of the Sight Log Book should be used for the calculations, the correct layout being as shown in the SUN example, page 32, at the end of this chapter.   The left-hand page is used for plotting the position line, as shown in Figs. 17 and 18.

9.   The intention is as follows :   To take an assumed position, and calculate from tables the altitude and azimuth of the sun had it been observed from that position at the time of the sight.   Compare the calculated altitude with the actual sextant altitude, and plot the difference between them in nautical miles along the azimuth line from the assumed position, either " Away " or " Towards " the true azimuth direction of the sun (i.e. its G.P.).

10.   The first step, after entering the sight data and correcting the Watch Reading for Watch Error, is to find the sun's position on the celestial sphere at the time of the sight, in terms of its Hour Angle (G.H.A.) and Declination.

On the correct date page of the Air Almanac (reproduced in Appendix A, Table 1) enter the G.H.A. Sun table with the nearest tabulated value below that required ; in this example the time required is 10.25.37, thus 10.20 is the nearest tabulated value below, which gives a G.H.A. of 337°32'.   Also extract the sun's Declination, found on the same line in the Almanac as the G.H.A. just extracted : Declination 03°01' South. Now since the G.H.A. tabulated was for 10.20 hours, and the time of the sight was 10.25.37, there remains a further 05 mins. 37 secs. to account for.

This increment is used in the table on the inside front cover of the Almanac (Appendix A, Table 3) headed " Interpolation of G.H.A. Sun." Against 05 mins. 37 secs. will be found the G.H.A. increment of 01°24', which must be added to 337°32'. (Note well the extraction rule at the bottom of the interpolation table, which applies to many similar astro-tables.)

11. Having obtained the G.H.A. and Declination of the sun at the moment of sighting, a correction of longitude must be made to obtain the L.H.A. or Local Hour Angle of the sun. The next step is, therefore, to decide upon the assumed position for which the calculated altitude will be obtained. Any convenient position may be selected within approximately one degree of latitude and longitude from the D.R. Position. It is usual to select the nearest whole degree of latitude to the D.R. Position, and a longitude such that when added or subtracted from the G.H.A., a whole number of degrees will be obtained for the L.H.A.

In this case a longitude of 05°56'W is close to the D.R. longitude, and when subtracted (" Longitude WEST, Greenwich Hour Angle BEST ") from the G.H.A. of 338°56', it gives a L.H.A. of 333°. (Had the longitude been East, then the sign would have been plus, to make the G.H.A. " Least.")

Three arguments have been obtained with which to enter the Astronomical Navigation Tables : Latitude 51° North, L.H.A. 333° and Declination 03°01' South. Since Hour Angles, involving meridians, have only been used in the working so far, the latitude has not yet entered into the calculations, Hour Angles being unaffected by change of latitude.

12. The Astronomical Navigation Tables (later referred to as A.N. Tables) are split up into volumes covering a belt of 5° of latitude each ; in the example Volume L is selected, covering 50° to 54° North or South. The book is divided into two main sections by a thick green page. In the first half are tables for the selected Declinations of certain stars ; in the second half are tables of Declination covering every whole degree from 0° to 28°. In both cases the tables give the altitude and azimuth, given the three factors Declination, Latitude and L.H.A.

13. In the example the sun's Declination is 03°01' South ; entering the second half of the book, select the page labelled 3° (see Appendix A, Table 7), since the whole number of degrees below the value required is always used. At the top of the page is found the statement " 3° Declination

SAME name as Latitude," and on the following page "3° Declination CONTRARY name to Latitude." In this case, the Declination being South and the latitude North, the name is Contrary, and the second 3° page is selected.

Using an assumed latitude which is the nearest whole number of degrees to the D.R. Latitude, the table is entered on the 3° Contrary name pages with the arguments 51° (Latitude) and 333° (L.H.A.). The L.H.A. is first located down the side columns of either page, and 51° along the top locates the actual column of the table in which the answer will lie. Opposite these two values are found the Tabulated Altitude, 31°18', a correction " d,"−56', and the Tabulated Azimuth, 148°T. The correction " d " allows for interpolation of the Declination, being the difference in altitude between 3° and 4° Declination at a constant L.H.A. Since a Declination of 03°01' is required, the correction will be 01 sixtieths of −56. This may easily be computed by reference to the table on the last page of the A.N. Tables (see Appendix A, Table 12). Read off 56' along the top of the table, and 01 down the side (or vice versa). Opposite these values take out 01', which is applied as a correction to the Tabulated Altitude according to the sign of " d."

After extracting the azimuth of 148°T, the value must be checked according to the rules at the bottom of each page of the table, since the tabulated value may be east or west of north according to whether the body is rising or setting, and it is convenient always to plot the azimuth as north and east.

14. In the final step, the fully corrected Observed Altitude is written below the Calculated Altitude, and the smaller subtracted from the greater to give the Intercept. The Intercept is called Towards since the Observed Altitude is greater than the Calculated Altitude.

15. To plot the position line on the map, first locate the assumed position—51°N, 05°56'W—and draw through this point the azimuth line, producing it in the reciprocal direction (see Fig. 18). Mark the true azimuth direction by a suitable sign, such as a small figure of the sun, to indicate the direction of its Geographical Position.

Lay off the Intercept along this azimuth line, " Towards " the true direction of the sun's G.P., being a length of 15' on the latitude scale. The final position line is drawn through this point at right angles to the azimuth

line, and is labelled correctly, as shown in the figure. The " Sight Error " is the perpendicular distance between the position line and the aircraft's position at the time of the sight ; the latter, however, will be unknown except in the case of sights taken for practice purposes.

Working Star Sights.

16. One of the first steps in the previous example was to find the Hour Angle and Declination of the sun before entering the A.N. Tables to find the Altitude and Azimuth for the assumed position. In view of the close relationship between the sun and earth and the considerable daily movement of the earth around the sun, the Hour Angle of the latter body was tabulated specifically and the changing Declination given for each hour of G.M.T.

In the case of stars, had the same procedure been adopted, every star would require specific tabulation for its hour angles, with the result that the almanac would become far too unwieldy. Furthermore, they are all exceedingly far away, and for navigational purposes are fixed on the celestial sphere in permanent positions that do not vary. It is thus possible to take a fixed point of reference on the celestial sphere and measure the angular distance that each star lies west of it. If the G.H.A. of this point is tabulated in the almanac, then the G.H.A. of any particular star may be obtained by adding the fixed angle of the star's meridian west of the meridian of the reference point.

17. This point of reference has been agreed upon by astronomers and navigators alike, and is called the First Point of Aries (since it lay in the constellation Aries at the time when it was chosen—see Chap. 5, para. 16).

The fixed angle which is measured westwards from the meridian of the first point of Aries to the meridian of any star is known as the Sidereal Hour Angle (S.H.A.) of the star. (First point of Aries is usually referred to by the Zodiacal sign of Aries, thus Υ.)

· 18. From the above reasoning, and from Fig. 13—

$$\text{GHA}\,\Upsilon + \text{SHA}* = \text{GHA}*$$

thus $\quad \text{GHA}\,\Upsilon + \text{SHA}* \pm \text{Longitude} = \text{LHA}*.$

19.   Since the stars are fixed in this way on the celestial sphere, their Declination will remain constant (the earth rotating on its axis will not alter the Declination), thus a star's position may be defined in terms of its S.H.A. and Declination.

On the inside front cover of the Air Almanac will be found a list of the stars suitable for sextant observation (see Appendix A, Table 3).   Each star has a reference number from 1 to 50, and the Magnitude, S.H.A. and Declination are tabulated alongside.
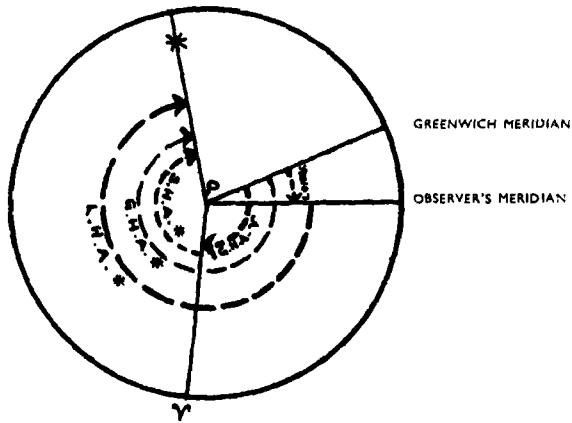
Fig. 13.

The Magnitude, or measure of brightness of the stars, rather unexpectedly decreases in numerical value with increase in brightness of the stars.   Thus SIRIUS, brightest of all stars, has a magnitude of −1.6, while ALPHACCA, the dimmest suitable for observation, has a magnitude of 2.3.

Due to Precession (see Chap. 5, para. 1), the S.H.A. and Declination of all the stars are very gradually changing in value, thus each issue of the Air Almanac shows a slightly different value for these two quantities.

EXAMPLE—Star Sight.

20.   On the night of October 1st—2nd, a navigator whose approximate D.R. Position was 51°18′N, 01°10′E, observes the mean altitude of VEGA to be 30°10′, his G.M.T. watch reading 23 hrs. 44 mins. 10 secs.

The watch was 12 seconds fast, and the Sextant Correction at this altitude −1′.

It is required to plot the position line passing through the observer.

21. The working is shown in the Star Example, page 34, at the end of this chapter. Proceed as with the previous sun sight in laying out the headings, and applying the watch error to obtain the correct G.M.T.

Extract the G.H.A. Υ from the correct date page of the almanac (see Appendix A, Table 1) in the same way as for the G.H.A. sun, interpolating 3 mins. 58 secs. in the table on the front cover (Appendix A, Table 3). Extract the S.H.A. of VEGA from the star list, and add together G.H.A. Υ + increment + S.H.A.* to give the G.H.A.*. Now apply an assumed longitude, such that when added (east longitude) the L.H.A. becomes a whole number of degrees. If the total exceeds 360°, then 360° may be subtracted without altering the value of the Hour Angle.

Turn to the A.N. Tables, first half, which consists of 22 divisions, one for each Group One star listed in the Almanac. VEGA being star No. 22, is found on the page labelled with this number (see Appendix A, Table 11). Ensure that " North Latitude " is stated at the top of the page, and proceed as before to extract the Altitude and Azimuth.

22. *Note.*—Whereas in a sun sight the Declination tables were tabulated for each consecutive whole degree, and the minutes of Declination were interpolated separately, the star tables have been constructed to give the exact Declination of the named stars ; thus interpolation is unnecessary and column " d " has been omitted.

In its place a new correction " t " allows for Precession of the earth, which is not appreciable for several years to come in the case of most stars. (Chap. 5, para. 1.) The reference table is on the inside front cover of the A.N. Tables.

23. The above method is only applicable to the 22 Group One stars. All the listed stars of Group Two in the Almanac have Declinations less than 29°, thus falling within the limits of the Declination tables used for the sun. These stars are worked in the same way as for the sun, by selecting the correct Declination page, turning to " Contrary " or " Same " name, and interpolating the minutes of Declination against " d."

24. The third group of stars listed in the Almanac cannot be used when working with the A.N. Tables, with the exception of the special case for POLARIS—see para. 30 of this chapter. These stars may, however, be used with other tables that are available such as Dreisonstock's Tables

(H.O. 208.)   It is suggested that the first two groups are adequate for all normal purposes.

Working Planet Sights.

25.   VENUS, JUPITER, MARS and SATURN are the only planets suitable for observation by sextant.   Of these, the first two are usually very brilliant objects in the sky, easily identified with an approximate knowledge of their positions, and often providing assistance when conditions are poor for the stars.   Mars and Saturn are useful objects, although at certain times when they are far from the earth they become too dim for sighting.

Since the planets revolve around the sun in orbits similar to that of the earth, they are not fixed on the celestial sphere, but move gradually among the stars, taking up positions in the constellations which are sometimes apt to confuse the observer when searching for a particular star in their vicinity. They may be recognised, however, by their steady light in contrast to the " twinkling " of the stars.

Space is provided in the Almanac for the tabulation of G.H.A. Tables for the three most suitable planets, or in some cases less when they are not available during the period of the night.   The G.H.A. is given for each hour of G.M.T., and interpolation for fractions of an hour is carried out in the large table headed " Interpolation of G.H.A. Planet " at the extreme end of the Almanac.   (Appendix A, Table 5.)

In all other respects the procedure is straightforward ; since all the planets lie within a narrow belt around the sun, their Declinations remain small, and the second part of the A.N. Tables may be used—again as in the case of sun sights.

EXAMPLE—Planet Sight.

26.   On the night of September 30th–October 1st, a navigator whose approximate D.R. Position is 52°55′N, 04°52′W, observes the mean altitude of JUPITER to be 47°42′, his G.M.T. watch reading 04 hrs. 46 mins. 05 secs.

The watch was 3 mins. 50 secs. slow, and the Sextant Correction at this altitude −4′.

It is required to plot the position line passing through the observer.   (See Planet Example, page 36, at the end of this chapter.)

Working Moon Sights.

27. The moon is available for observation by sextant at many times of the day and night, and may often be used at times when the stars are obscured by mist or thin cloud. When the moon is only partially illuminated (" horned ") care must be taken that the outside curve of the moon and not the shadow curve is located to be concentric with the bubble of the sextant.

Moon data are tabulated on the left-hand pages of the Air Almanac (see Appendix A, Table 2), and the interpolation table for the G.H.A. is on the back of the outer flap at the end of the book (see Appendix A, Table 4).

The Altitude and Azimuth for the assumed position are found in the second half of the A.N. Tables as for the sun and planets.

28. The Declination has been tabulated for every ten minutes of G.M.T. as against every hour for the sun and planets. This is on account of the moon's rapid change of Declination as it revolves around the earth. The nearest tabulated value below that required (e.g. 09.10 where 09.13.30 is required) should always be used when reading off the G.H.A. and Declination values.

The additional correction Parallax in Altitude explained in Chap. 1 is given down the centre of each moon page of the Almanac, and this should be ADDED to the sextant altitude together with the other small corrections. The daily tabulations of P. in A. are necessary because the distance between the moon and the earth varies slightly, with a resulting slight variation in the parallax.

EXAMPLE—Moon Sight.

29. On the night of September 30th–October 1st, a navigator whose approximate D.R. Position is 50°28′N, 06°05′E, observes the mean altitude of the MOON to be 54°53′, his G.M.T. watch reading 05 hrs. 41 mins. 45 secs.

The watch error was nil, and the sextant correction at this altitude −3′.

It is required to plot the position line passing through the observer. The working is shown in the Moon Example, page 38, at the end of this chapter.

The Pole Star.

30. A special case must be made of the star POLARIS ; at the present time it lies within approximately one degree of the North Celestial Pole, and the azimuth will always be within a degree of true north. Since astro position

lines are always at right angles to the line of azimuth, it follows that the POLARIS position line will be within a degree of the horizontal, and will indicate the observer's latitude.

Thus, THE ALTITUDE OF THE POLE STAR IS EQUAL TO THE OBSERVER'S LATITUDE. This is proved geometrically in Chap. 6, para. 13.

In the Marcq St. Hilaire method of plotting the position line, an assumed position was needed because the G.P. of the Star could not be included on the map. With POLARIS the G.P. is nearly at the Geographical pole of the earth, and the parallels of latitude printed on the map may be considered as circles of altitude for POLARIS.

31. However, the short distance between the pole star and the true Celestial Pole is sufficient to produce an error in altitude—and therefore latitude—of up to one degree, which is far outside the required limits of accuracy.

Since the pole star is displaced from the true axis of rotation of the earth, it will appear to rotate about the Celestial Pole like all the other stars. Its apparent rotation, however, will be about a circle of only one degree of Declination off the true pole, and a correction can easily be applied to the observed altitude to bring it to that of the true Celestial Pole and therefore the correct latitude of the observer.

This correction, known as " Q " Correction, will be nil when the pole star is at the same altitude as the true pole, but on one side of it, and will reach a maximum plus and minus value as it passes beneath and above the true pole. In Fig. 14, the value of " Q " is negative, since the altitude of POLARIS is greater than that of the true Celestial Pole. In Fig. 15, the value of " Q " is positive, since the altitude of POLARIS is less than that of the true pole.

A table is provided in the Air Almanac from which to obtain the value of " Q " at any time. Since the position of POLARIS relative to the true pole will vary with the Hour Angle of the First Point of Aries, the values of " Q " are tabulated against L.H.A. Aries (see Appendix A, Table 6).

EXAMPLE—Polaris.

32. On the night of September 30th–October 1st, a navigator observes the mean altitude of POLARIS to be 64°26', his G.M.T. watch reading 22 hrs. 10 mins. 00 secs.

His watch is 30 seconds slow, and the Sextant Correction at this altitude +2′.

Required to find his latitude at the time of sighting (see POLARIS Example, page 39, at the end of this chapter for working).

Enter the air almanac with the G.M.T., and extract G.H.A. Υ, adding the interpolated quantity in the usual way. Apply the D.R. longitude to obtain the L.H.A. Υ. Although the D.R. longitude may be considerably in error, a variation of two or even three degrees in the longitude will not appreciably alter the value of " Q."
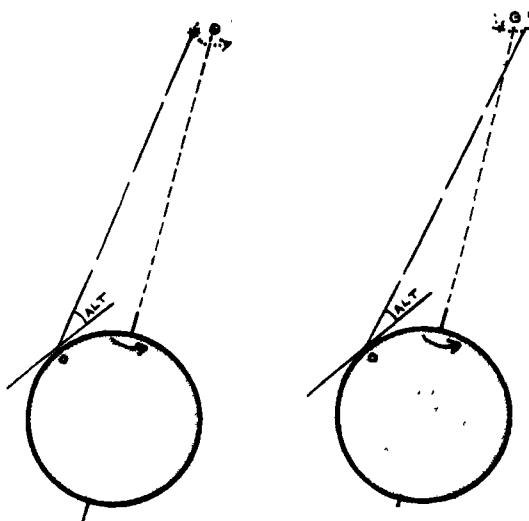
Fig. 14.   Fig. 15.

Enter the Pole Star Table on the inside flap of the Almanac (Appendix A, Table 6) with L.H.A. Υ, and extract the corresponding tabulated value of " Q." Add or subtract this value, according to sign, to the Sextant Altitude, together with the Sextant Correction. (*Note.*—Refraction has been incorporated in the Pole Star Table, and must not be applied as a correction.)   The resulting Observed Altitude will be equal to the observer's Latitude.

The working for the Pole Star is considerably shorter than for any other type of sight, and the result is easily plotted as a horizontal position line at the correct latitude.

It is unfortunate that Polaris is not a very bright star, having a magnitude of only 2.1, but it will be appreciated that navigators are exceedingly fortunate in having any star of workable magnitude within less than two degrees of the Celestial Pole. In a few thousand years it will no longer occupy its present position, and will thus pass out of the limelight for some 26,000 years, when it will once again assume its important role in navigation for a limited period. (Chap. 5, para. 1.)

33. These two final examples are to illustrate the effect of an extreme longitude, which may

(*a*) cause doubt in the reading of a watch with a 12-hour face ;

·or (*b*) cause a change between the Local and Greenwich date.

The same volume of the Astro-Navigation Tables has been used ; other latitudes may be worked from their respective volumes.

34. " On a flight across the JAPAN SEA, on local date OCTOBER 1st, at approximate Zone Time, 23.40 hours, a navigator was in D.R. Position, 42°10′North, 135°40′East. At G.M.T. Watch Reading, 02.45.10 (watch 2 mins. 30 secs. fast), the mean altitude of POLARIS was 43°06′ (Sextant Correction −1′). Required to find his Latitude at the time of sighting."

See " EXAMPLE—Japan Sea," page 40, at the end of this chapter for full working.

35. " On a flight from the FALKLAND ISLANDS, South America, on local date SEPTEMBER 30th, at approximate Zone Time, 22.10 hours, a navigator was flying in D.R. Position 51°45′South, 57°30′West. At G.M.T. Watch Reading 02.10.05 (watch 3 secs. slow), the mean altitude of ACRUX was 25°54′ (Sextant Correction −5′). Required to plot the resulting position line."

See " EXAMPLE—South America," page 42, at the end of this chapter for full working.

The Sight Log Book.

36. It is usual practice to keep a record of all astro sights taken, in the form of a log book which eventually becomes a means of assessing the experience of any individual navigator. Such a record also provides valuable information concerning Sextant Errors and the navigator's Personal Error.

The log book may conveniently take the form of alternate pages of squared and plain paper, the squared pages being used for plotting the position lines, and thus recording the work carried out on the mercator plotting sheet or map.

Several types of pro-formæ have been designed to simplify the process of calculation and avoid mistakes in the air. Many such forms tend to be over complicated, and often suffer the disadvantage that a different form is required for each type of heavenly body. The layout shown in Fig. 16, which is in the form of a rubber stamp, is equally applicable to all types of sight calculation, and has been kept as simple as possible without actually leaving out any essentials.

Date	M.W.R.		Body	D. R. Position	No.	Air
	Corr'n ..					
	G.M.T.				No.	Ground

		N	Sex. ALT.	
G.H.A.	Dec.	S	Sex. Corr.	
			Dome Refr.	
Incr.			P. in A. (Moon only) +	
SHA (Star)				
			Obs. ALT.	

		ALT.	AZ.
G.H.A......			
Ass. Long.	Ass. Lat.	Tab.	
		Inc. ' d '.	Tab. AZ.
		———	
L.H.A.		Cal. ALT.	
		Obs. ALT.	
		———	True AZ.
		INTERCEPT	
		AWAY TOWARDS	

Fig. 16.

37. A new problem presents itself in plotting the position line on squared paper, since the mercator projection of the earth becomes elongated

in latitude with distance from the equator. If the position lines were plotted using the squares of the paper as a graticule, then the latitude and longitude scales would each be different, and the plotting would not be accurate.

The geometric method of constructing a mercator graticule is to erect an angle, using any convenient parallel as a base line, equal to the latitude. This sloping line then becomes the latitude constructional scale, and since all measurements on the map in nautical miles are made along the adjacent latitude scale, the sloping line becomes the datum for measuring all distances.
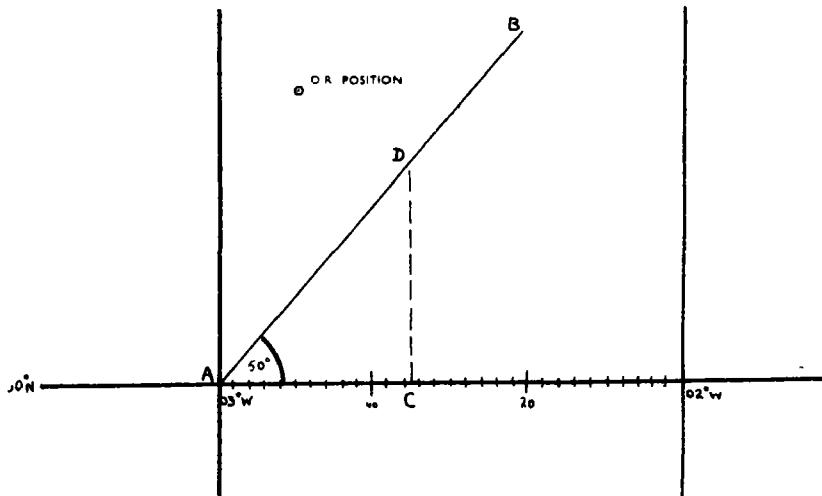
Fig. 17.

In Fig. 17, an angle of 50° has been erected to provide a scale line for latitude 50°. Suppose a D.R. Position of 50°25′N, 02°50′W is to be plotted. The 25′ of latitude is measured along the sloping line AB by taking the distance from A along the base line to C, where the respective vertical line of the squared paper cuts the sloping line at D. The distance AD is then laid off along the latitude scale from A ; the longitude is measured in the normal way along the horizontal base line, since the longitude scale on mercator remains constant.

If a distance is to be measured on the graticule, then the required length is laid along the sloping line from A, and a perpendicular dropped on to the base line, where measurement is made horizontally from A.
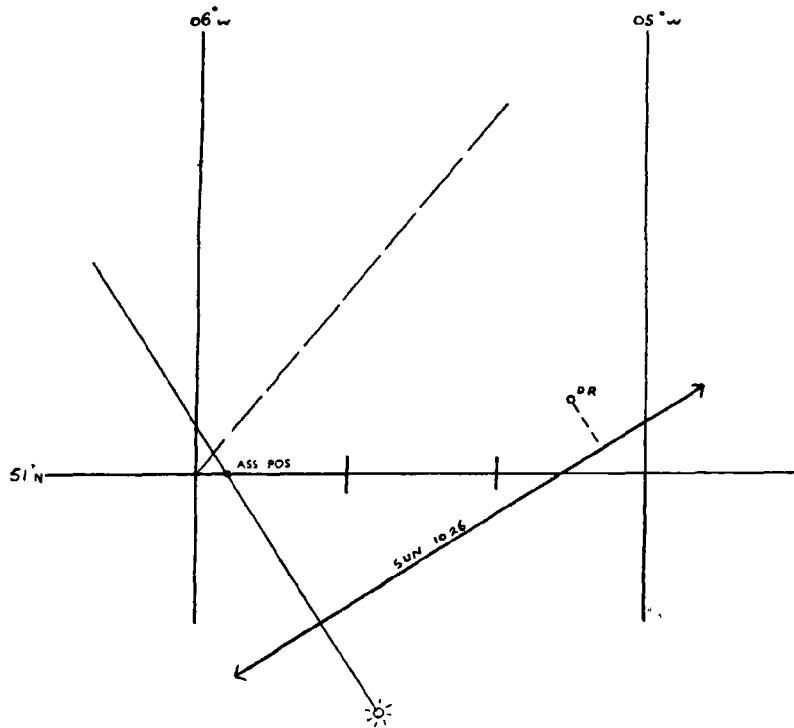
Fig. 18.

EXAMPLE—Sun Sight.

DATE	M.W.R. ......10.25.30 Corr'n .... +7 ——— G.M.T. 10.25.37	BODY	D.R. Position
1st Oct.		Sun	51°06'N, 05°10'W

GHA Sun ......337°32'. DEC .....3°01'S.
Incr.   .... 1°24'

        338°56'
Ass. Long.   ...... 05°56'W. Ass.Lat...51°N.

LHA Sun.........333°

Sext. Alt..........31°29'
Sext. Corr........ +3'

Obs. Alt.   ......31°32'

Tab. Alt. ....31°18'   Tab. Az. ....148°
'd' .... −1

Calc. Alt. ....31°17'   True Az.   ....148°
Obs. Alt. ....31°32'

INTERCEPT ......   15' Towards

For reference tables, see Appendix A, Tables 1, 3, 7 and 12.

See Fig. 18.
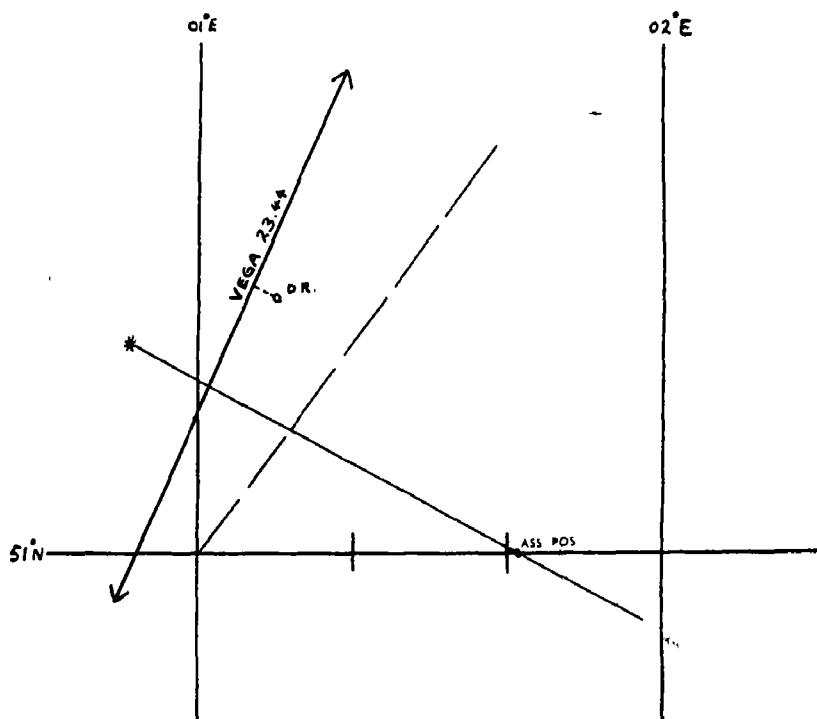
Fig. 19.

EXAMPLE—Star Sight.

DATE	M.W.R. ......23.44.10.	BODY	D.R. Position
1st Oct.	Corr'n .... − 12	Vega	51°18′N, 01°10′E
	G.M.T. 23.43.58		

GHA Aries ......005°04′
Incr.   .... 1°00′
SHA Star.........081°15′

GHA Star ......087°19′
Ass. Long. ...... 01°41′E. Ass.Lat. 51°N.

LHA Star ......089°

Sext. Alt..........30°10′
Sext. Corr........ −1′

Obs. Alt..........30°09′

Tab. Alt. ....29°41′   Tab. Az. ....064°
' t '.................... 0

Calc. Alt. ....29°41′   True Az. ....296°
Obs. Alt. ....30°09′

INTERCEPT ...... 28′   Towards.

For reference tables, see Appendix A, Tables 1, 3 and 11.

See Fig. 19.
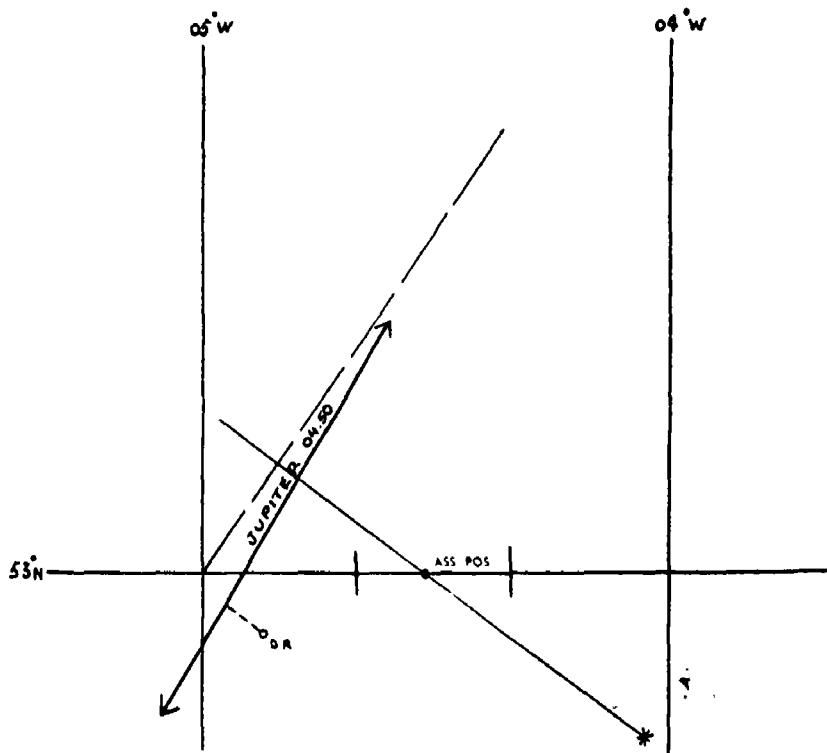
Fig. 20.

EXAMPLE—Planet Sight.

DATE	M.W.R. 04.46.05	BODY	D.R. Position
	Corr'n .... +3.50		
1st Oct.	———	Jupiter	52°55'N, 04°52'W.
	G.M.T. 04.49.55		

GHA Planet ...315°00'. DEC. 21°37'N.   Sext. Alt.........47°42'
Incr. .... 12°30'   Sext. Corr....... −4'
              —————
           327°30'   Obs. Alt.........47°38'
Ass. Long. ...... 04°30'W. Ass.Lat. 53°N.   —————
      —————

LHA Planet......323°
 —

      Tab. Alt. ....47°19'   Tab. Az. ....124°
      'd' .... +31'
            —————
      Calc. Alt.............47°50'   True Az. ....124°
      Obs. Alt. ....47°38'
         —————
      INTERCEPT ...... 12' Away.

For reference tables, see Appendix A, Tables 1, 5, 9 and 12.

See Fig. 20.
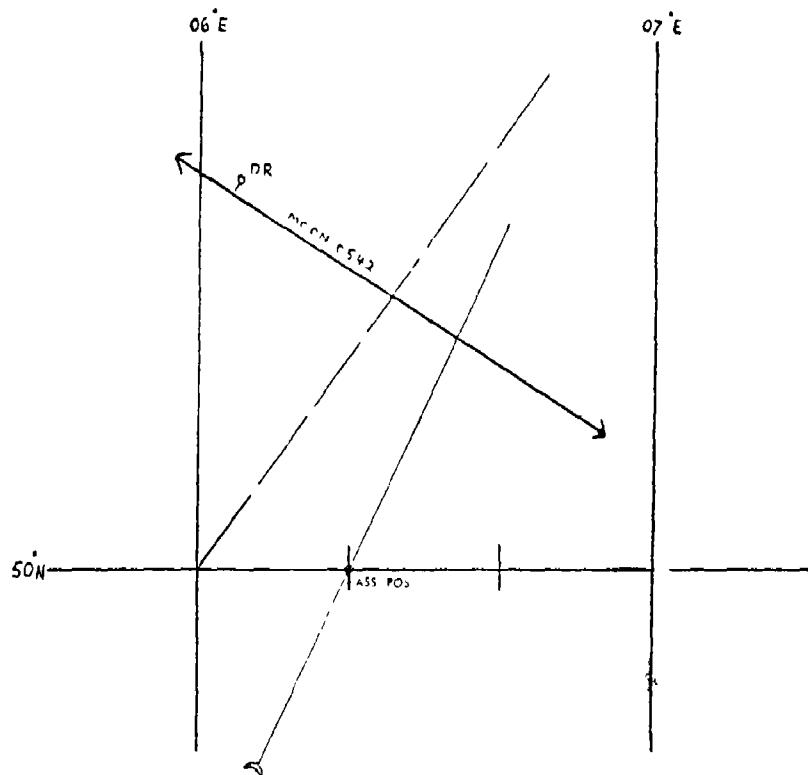
Fig. 21.

EXAMPLE—Moon Sight.

DATE	M.W.R. 05.41.45	BODY	D.R. Position
	Corr'n 0		
1st Oct.		Moon	50°28′N, 06°05′E
	G.M.T.........05.41.45		

GHA Moon ...010°15′. DEC. 18°28′N.   Sext. Alt..........54°53′
Incr. ....   25′   Sext. Corr........ −3′
                                                 Par. in Alt.   ... +31′
                010°40′
Ass. Long. ...... 06°20′E. Ass. Lat. 50°N.   Obs. Alt..........55°21′

LHA Moon ...017°

Tab. Alt. ....55°14′   Tab. Az. ......151°
'd' .... +26′

Calc. Alt. ....55°40′   True Az. ......209°
Obs. Alt. ....55°21′

INTERCEPT ......   19′ Away.

For reference tables, see Appendix A, Tables 2, 3, 4, 8 and 12.

See Fig. 21.

EXAMPLE—Polaris.

DATE	M.W.R. 22.10.00	BODY	D.R. Position
	Corr'n.. ..... +30		
1st Oct.		Polaris	63°35′N, 05°10′E.
	G.M.T. 22.10.30		

GHA Aries	.342°30′	Sext. Alt. ....64°26′
Incr.	. 08′	Sext. Corr......................... +2′
		'Q' Corr. .... −48′
	342°38′	
D.R. Long. .... 05°10′E.		OBSERVER'S LATITUDE 63°40′

LHA Aries ....347°48′

For reference tables, see Appendix A, Tables 1, 3 and 6.

EXAMPLE—Japan Sea.

DATE	M.W.R.	....02.45.10	BODY	D.R. Position
(Local)	Corr'n..	..... − 2.30		
1st Oct.			Polaris	42°10′N, 135°40′E
	G.M.T.	......02.42.40		

Time check—Zone time................23.40.00 approx. on Oct. 1st.
                Longitude .... 9.03.00 (converted to time)

           Approx. G.M.T. ....14.37.00 on Oct. 1st.

Therefore G.M.T. by watch is 02.42.40 plus 12 hrs.
               or 14.42.40

GHA Aries ....229°42′			
Incr. .... 40′	Sext. Alt.....................43°06′		
	Sext. Corr. .... − 1′		
230°22′	' Q ' Corr. .... − 58′		
D.R. Long. ....135°40′E.			
	Obs. LATITUDE ......42°07′		
366°02′			
less ...360°			
LHA Aries ....006°02′			

For reference tables, see Appendix A, Tables 1, 3 and 6.

Note.—The D.R. Longitude is converted to ' time ' (15° equals 1 hour), and applied to the Zone Time to check the approximate G.M.T. and Greenwich Date.

Thus: Longitude 135°40′E=9 hrs. 3 mins. approx. Since when ' Longitude is East, Greenwich time is least,' this value is subtracted from the Zone Time to obtain an approximate G.M.T. of 14.37 hours.

The face of the G.M.T. watch gave 02.42 hours, thus the time check shows that this is in error by 12 hours, and the Watch Time should be read as 14.42.40.

Note that subtracting 9 hours from 23.40 hours does not involve crossing midnight (24.00 hours), therefore the date is correct.

58°W

57°W

ACRUX   02.10

D.R

ASS POS

52°S
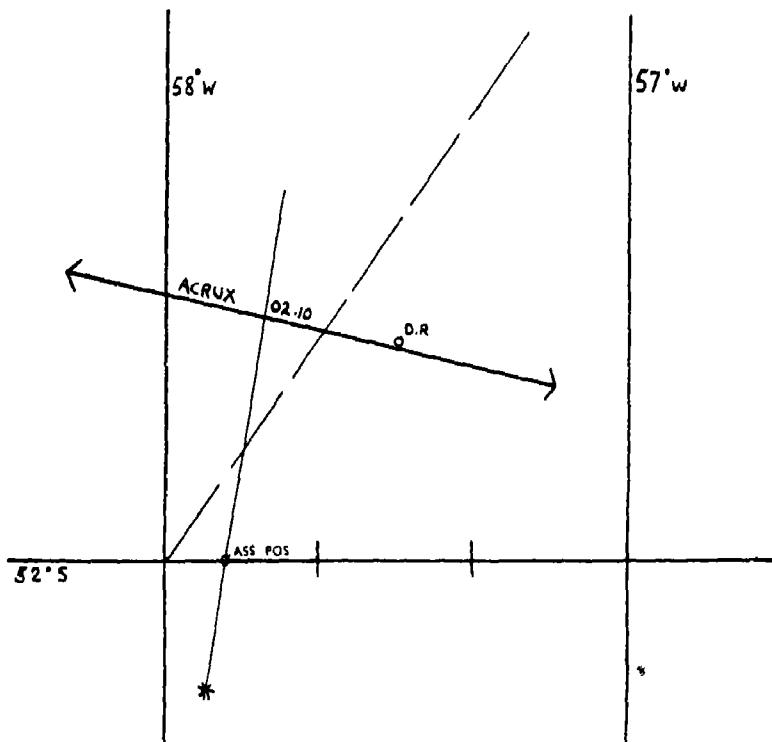
Fig. 22.

EXAMPLE—South America.

DATE	M.W.R. 02.10.05	BODY	D.R. Position
(Local)	Corr'n .... +3		
30th Sept.		Acrux	51°45'S, 57°30'W
	G.M.T. 02.10.08		

Time check ......Zone time ....22.10.00 approx. on Sept. 30th.
          Longitude 3.50.00

    Approx. G.M.T. 02.00.00 on Oct. 1st.

Therefore the G.M.T. by watch is correct.

GHA Aries ......041°41'	Sext. Alt.........25°54'
Incr. .... 02'	Sext. Corr........ − 5'
SHA Star.........174°09'	
	Obs. Alt.........25°49'
GHA Star ......215°52'	
Ass. Long. ...... 57°52'W. Ass. Lat. 52°S.	
LHA Star ......158°	

Tab. Alt. ....26°06'	Tab. Az. 011ᶜ
' t '.................... 0	
Calc. Alt. ....26°06'	True Az. 191ᶜ
Obs. Alt. ....25°49'	
INTERCEPT ...... 17' Away.	

For reference tables, see Appendix A, Tables 1, 3 and 10.

See Fig. 22.

NOTE.—In the previous Polaris example, the midnight mark was not passed when moving from Zone Time to G.M.T. In the above example, however, the approximate Zone Time is 22.10 hrs. on Sept. 30th, and the longitude of 3 hrs. 50 mins. must be added according to the rule for west longitude ' Longitude West, Greenwich Time Best.' 22.10 plus 3 hrs. 50 mins. gives 02.00 hrs. G.M.T. on the next day—Oct. 1st, the midnight mark having been crossed.

STAR IDENTIFICATION.

1.   In this chapter the movements of the stars and planets on the celestial sphere will be explained, and a plan evolved by which the important stars may be grouped and studied, using the special star maps in Figures 25—28. The suggested groupings are not the constellations which are used by astronomers, for these are based in many cases on Greek and Roman mythology, and are not suited to the navigator's requirements.   Instead, the stars have been arranged in the diagrams ignoring the constellation boundaries altogether unless they happen to be suitable, such as in the case of Ursa Major, The Plough.   In this way, every star of navigational value in mid-northerly latitudes may be studied by reference to its position in, or adjacent to, the three patterns, The Plough, Orion and the Vega-Deneb-Altair triangle.

The Movements of the Stars.

2.   There are two main causes for the apparent movements of the stars, and they are both due to the earth's own revolutions :—

> (a) around its own axis,
> and (b) around the sun.

There is no appreciable movement of the stars due to any other cause which need concern the navigator at this stage.   Time-of the day (earth's rotation around its axis) and date of the year (earth's revolution around the sun) are the only two values which must be known in order to determine the position of the celestial sphere, or any single star, from a known point of observation.

The effects of these two causes will be studied separately.

(a) Earth's Rotation Around its Axis.

3.   The earth rotates on its axis from west to east, giving the stars an apparent rotation in the opposite direction.   If viewed by an observer somewhere outside the celestial sphere, all the stars would appear stationary, and somewhere in space the earth would be seen spinning slowly on its axis. But the observer is in fact situated on the surface of this spinning earth, and
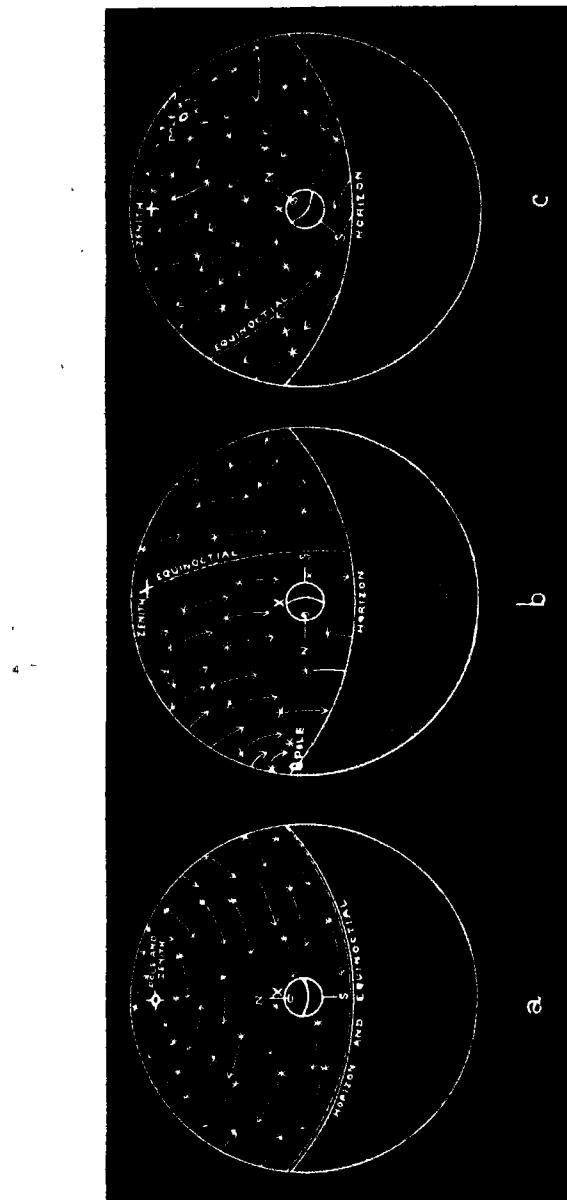
PATHS TRACED BY THE STARS EACH NIGHT ACROSS THE SKY OF AN OBSERVER (MARKED X) SITUATED

(a) At the Geographical Pole,
(b) On the Equator,
and (c) At latitude 50°N.

Fig. 23.

the location of the stars as seen by him will be constantly changing. Furthermore, the paths traced by the stars across the observer's sky will appear entirely different from various positions, or latitudes, on the earth. If the observer is at the north (or south) pole of the earth, he is situated right on the axis of rotation, as though sitting on the roof of a roundabout exactly over its axis. All the objects on every side of the roundabout appear to rotate around him, maintaining their same height or altitude relative to his eye. Likewise, from the pole, all the stars appear to travel around the observer horizontally, never changing their altitude, as in Fig. 23a. Stars nearly overhead are close to the celestial pole and trace small circles around it, while stars closer to the equinoctial travel around nearer the horizon and always at the same altitude. No star will ever rise or set, and only stars north of the equinoctial will be visible from the north pole, and those south of the equinoctial from the south pole, no matter what the time of year.

4. But if the observer stands on the equator, as in Fig. 23b, and faces east, he will have the north and south poles symmetrically on either side of him, and the stars will rise up vertically from the eastern horizon, follow their own arcs about the poles either overhead if they rose exactly in the east, or to the north or south of the observer according to their declination, and sink down again in the west. This time the movements are mostly vertical, and the altitudes changing rapidly, except when the stars are crossing the observer's north-south celestial meridian, having reached their maximum altitude.

5. A more probable case, however, would be where an observer is situated at some intermediate latitude, say 50° north, and here the picture becomes more difficult to visualize. If we continue to place the observer's zenith or overhead point at the top of the diagram, as in Fig. 23c, then the north celestial pole will lie to the north of him, and at an angle of 90°—50° from the zenith. Stars near to the pole will trace small circles around it and never sink below the horizon. But stars closer to the equinoctial will disappear from the sky for a period, since their arcs will be cut by the observer's horizon line. From the diagram it will be seen that a section of the south declination stars are visible for rather shorter periods, always remaining in the south-eastern, southern or south-western part of the sky.

6. In the examples illustrated by Figs. 23a and 23c, it was shown how certain stars never fall below the horizon, because their own fixed distance from the pole is less than the distance from the observer's horizon to the pole.

These stars are known as CIRCUMPOLAR STARS, and are of special importance to the navigator because they are always visible, and become familiar features in the sky, such as the Plough, which is well known to all who dwell in northern latitudes.

To calculate whether a certain star is circumpolar, its declination should be compared with the value 90°—observer's latitude. If the declination is the greater value, then the star is circumpolar. If the declination is less, then it must pass below the horizon during part of its daily passage.

(b) *Earth's Revolution around the Sun.*

7. Thus far we have only considered the movements of the stars which are apparent from hour to hour, and which make it necessary to take sextant observations to the nearest second of time. If, however, the stars are observed
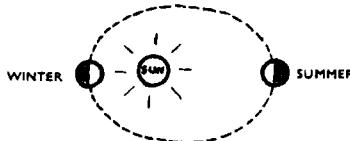
Fig. 24.

on scattered nights throughout the year at one particular time such as midnight, it will be found that a second less obvious progression has been taking place which gradually changes the times of rising and setting of the stars, and the periods of the year during which they are visible. This secondary movement is caused by the earth's revolution around the sun, and is explained by Fig. 24.

The earth makes one complete revolution around the sun each year, and as it moves round its orbit the part of the sky visible from the darkened or night half of the earth at midnight each night is gradually changing. In the figure, an observer at midnight in Winter sees the stars on the left of the

diagram, but by Summer the earth has moved to the opposite end of its orbit, and the observer at midnight sees the stars on the right of the diagram. Excluding the circumpolar stars, those which he saw in Winter are now above the horizon during the daylight hours and therefore invisible at midnight.

Thus, at a given time each night, the observer is facing out into space in a slightly different direction, because we are circling around the sun from which our time is measured. The stars will appear to shift forward a little each night along their respective declination circles, in reality the earth having turned through a little more than one rotation on its axis. This is fully explained in Chapter 5, para. 10.

8. Due to this gradual shift of the heavens, each group of stars has one period or season at which it is on the observer's meridian at midnight, and thus good for observation for most of the night. Orion, for example, is known as a Spring constellation, and is well placed in the sky throughout the Spring nights. Even circumpolar stars are often given seasonal annotations, although they never disappear, the season simply indicating when they have their greatest altitude at midnight.

Star Maps.

9. Since the stars remain in fixed positions on the celestial sphere, they may be mapped in the same way as land masses on the earth. Similar difficulties arise when showing large areas of a sphere on a flat sheet of paper, and various projections must be used according to the type of map required. A polar projection is perhaps the most satisfactory way of showing one whole hemisphere on a single map, since the distortion is equally distributed as distance from the pole is increased. But if the map is to include the equinoctial and a small belt of the opposite hemisphere, as in most planispheres and the star maps in this chapter, then considerable distortion is bound to occur towards the edges, where the scale must be larger than at the pole. Navigators will be familiar with the abnormal size of Africa or South America on a polar gnomonic projection.

Such maps of the earth are seldom of any real value because of this distortion, and projections are used which show much smaller areas on each map. But for astronomical purposes it is a great advantage to be able to show a large area of the heavens on one map, because the eye can see one whole hemisphere at any time—a very different situation to that of the

geographer.   It is fortunately not very serious that a polar projection increases its scale with distance from the pole, since we are not concerned with the shape or size of individual areas, but simply with the approximate relative positions of single points of light.   Stars projected on such a map provide a satisfactory means of studying their relative positions, provided the scale difference is remembered for stars far from the pole or point of tangency of the projection.

To compare a star map with the night sky, it must be remembered that the edge of the map is not the horizon line, and it may be necessary to tilt the map or turn it upside down before it corresponds with the position of the celestial sphere at that particular moment.   A glance at Fig. 25 will show how arbitrary are the edges of the three star maps of the northern hemisphere which follow.

To study a star map and compare it with the night sky, a device known as a Planisphere should be used, which superimposes the observer's horizon over the map, thus showing only those stars which are visible at the time in their true relation to the horizon.   Planispheres are discussed in para. 26 of this chapter.

THE STAR MAPS IN THIS BOOK.

10.   Fig. 25 shows a north polar projection of the celestial sphere. Superimposed on this small scale map are three rectangles, which indicate the boundaries of the three maps which follow on a larger scale in Figs. 26, 27 and 28.   Together these three maps cover the whole area of the northern hemisphere and a part of the southern hemisphere lying close to the equinoctial. By referring to the key map in Fig. 25 the relationship between each star diagram may be seen.

The stars have been shown as follows :

> All small magnitude stars unimportant to the navigator have been omitted, unless they assist in building up a design or pattern in the sky from which other bright stars are traced.

> The stars of first rate importance to the navigator are shown with large five-pointed stars and listed underneath in large type.

> The stars which may prove useful to the more experienced navigator are shown by smaller eight-pointed asterisks, and listed in small type.

> The small stars which are used as guides but never for sight-taking are shown as small dots.

KEY MAP.
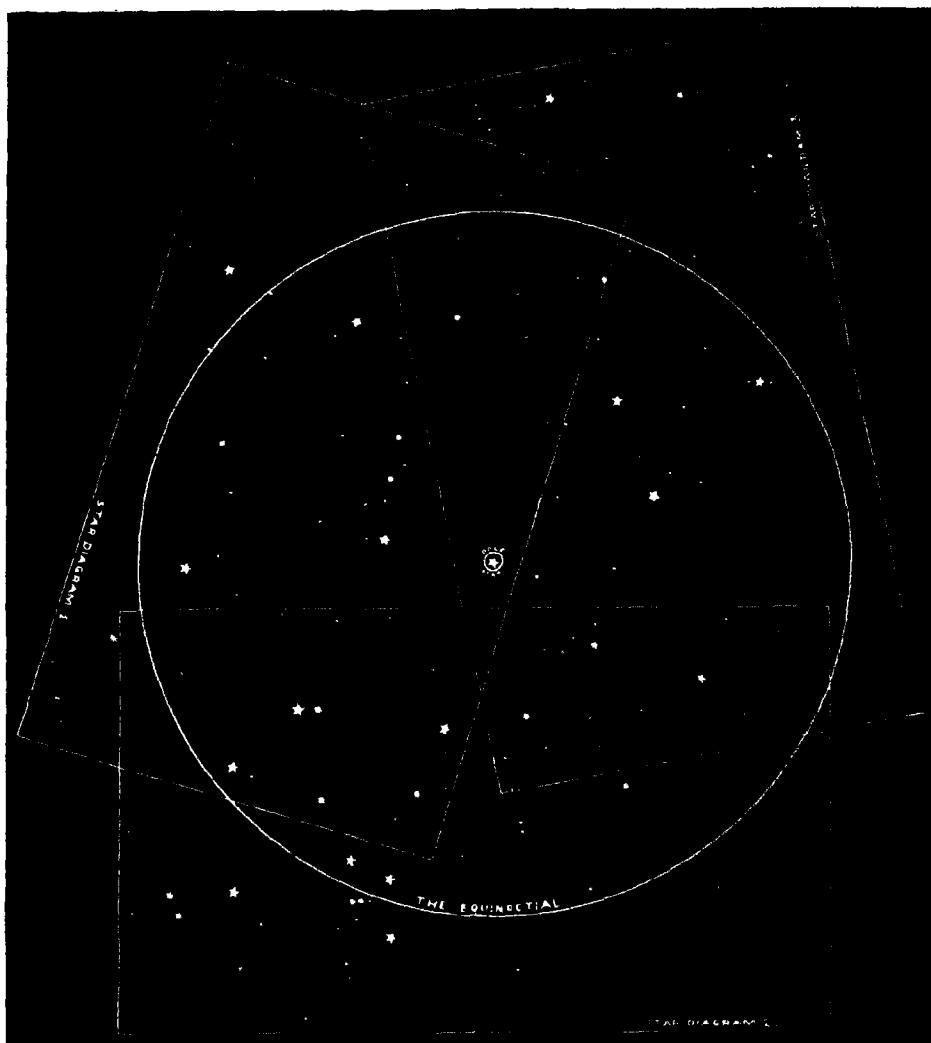
SHOWING THE RELATIVE POSITIONS OF THE THREE NORTHERN HEMISPHERE
STAR DIAGRAMS THAT FOLLOW IN FIGS. 26, 27 AND 28.

Fig. 25.

Star Diagram 1.   (Fig. 26).

11.   The well-known constellation or group of stars Ursa Major has been chosen as the central feature of the first star map to be lifted from the polar diagram in Fig. 25.   Undoubtedly the most characteristic and familiar feature of the sky in the northern hemisphere, this well-defined group is known by the various names : The Plough, The Great Bear, The Dipper or Charles' Wain (Charles' Waggon).   To navigators it is perhaps the most important feature in the whole sky, since a glance at its location and the angle at which it is tilted should be sufficient to fix the positions of all the other important stars.   For example, referring back to Fig. 25, the northern hemisphere may be considered as a clock face, using the pole star as the centre, and the " pointers " of the Plough as 12 o'clock.   Other groups may then be remembered by their positions on the clock, thus Orion is at 9 o'clock, Aquila, the Eagle (star Altair) between 3 and 4 o'clock, Cassiopeia at 7 o'clock, Virgo, the Virgin between 1 and 2 o'clock, and so on.   If the clock positions of the important stars are memorized, then at night if the Plough is first located and the position of 12 o'clock noted, all the other stars can be found, remembering that the pole star and not the zenith is the centre of the clock. Naturally, as the sky becomes more familiar, the stars may be recognised at once without this preliminary means of orientation.

12.   In Fig. 26 the Plough is seen to contain one important star and two secondary stars.   DUBHE, the brightest star in the constellation, is also the main " pointer " star to the pole.   If the line of the two pointers is extended northwards for about five times their distance apart, the stars POLARIS is located, a little over one degree from the true celestial pole.   Since Polaris is not a very bright star, the nearby pointers provide a ready means of locating it at all times, and particularly when the visibility is poor.

If the line of the two pointer stars is produced in the reverse direction, this time for about seven times their distance apart, the bright star REGULUS is found in the constellation Leo, the Lion.   Part of this constellation has the characteristic shape of a sickle, with Regulus lying in the handle.   The other stars in the constellation are not very bright however, and Regulus is more readily located by reference to the Plough pointers.

In the handle, or western extension of the Plough, the two secondary stars ALIOTH and BENETNASCH are found, the latter being the end star of the handle.   The curve of this handle section may be extended as in the
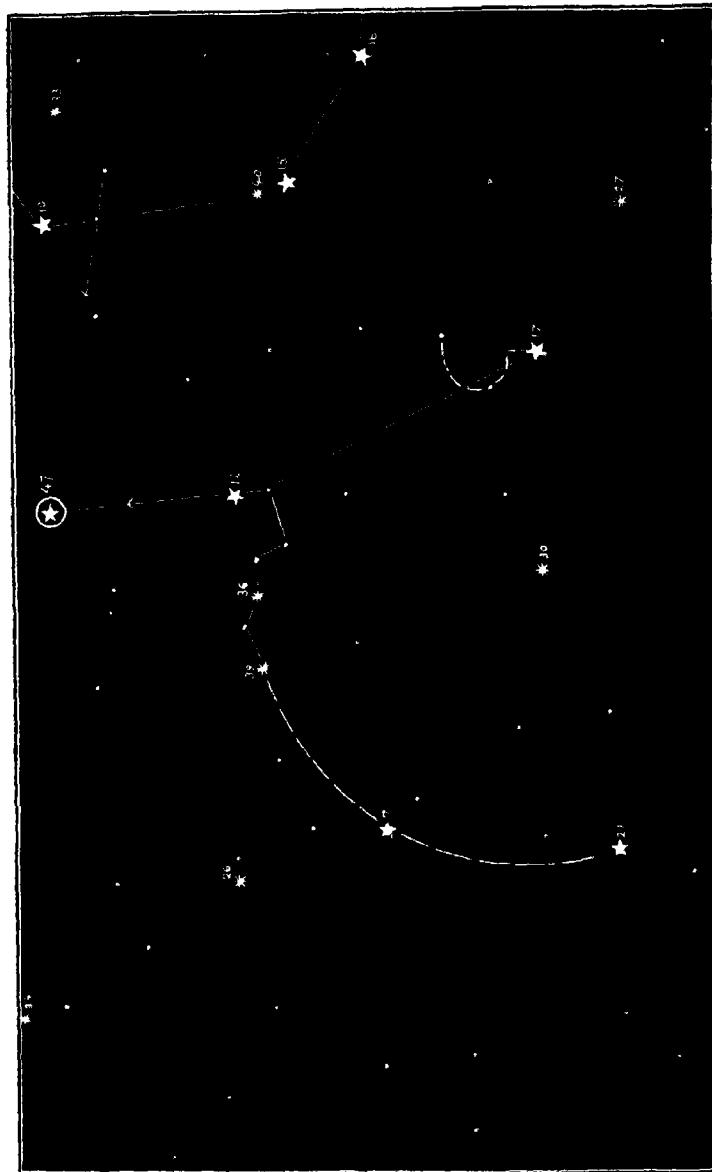
STAR DIAGRAM 1.—THE PLOUGH.

7. ARCTURUS	16. PROCYON	27. ALPHARD	36. ALIOTH
10. CAPELLA	17. REGULUS	30. DENEBOLA	39. BENETNASCH
12. DUBHE	21. SPICA	33. NATH	40. CASTOR
15. POLLUX	26. ALPHACCA	34. RAS ALHAGUE	47. POLARIS

Fig. 26.

diagram to locate first the bright star ARCTURUS, and further round the curve the star SPICA, these two being in the constellations Bootes and Virgo respectively.   At the geometric centre of this great curve is the secondary star DENEBOLA, in Leo.

Star Diagram 2.   (Fig. 27).

13.   The part of the sky richest in first magnitude stars is that in the region of the constellation Orion, the most striking formation in the sky after the Plough.   The three small stars in the belt of the mythical Greek hero Orion lie almost on the equinoctial (see Fig. 25).   This constellation will not, therefore, ever rise above an altitude equal to the observer's co-latitude, or about 38° for an observer in England.

14.   Three brilliant stars are found within the constellation of Orion. BETELGEUSE, a star which varies its magnitude, and has a noticeable reddish colour.   RIGEL, which is almost symmetrically opposite to Betelgeuse on the other side of the belt stars.   And BELLATRIX, which is adjacent to Betelgeuse.   These three stars are so bright that they all qualify for the classification known to astronomers as " super giants."

The three stars in the belt of Orion point exactly to the brightest star in the sky, SIRIUS, the " Dog star " in Canis Major, which is one of the most beautiful of all stars, flashing many brilliant colours.   Being 17° below the equinoctial, it only reaches suitable altitudes for sight-taking for short periods at certain times of the year.

Following around a great imaginary curve from Orion's belt, through Sirius, we come to a bright star PROCYON, in Canis Minor, which has a small partner adjacent to it making a useful recognition feature.   Further round the curve at 30° North declination are the two well-known stars POLLUX and CASTOR, called the Heavenly Twins, in the constellation Gemini.   Pollux is the brighter and the more suitable of the two for sight-taking.   Next around the curve we have CAPELLA, in Auriga, a brilliant white star at 46° North, and most valuable for navigation, since it is high enough in declination for astro use during most of its passage.   Apart from its position relative to Orion, certain small stars close to it help in identification on a clear night.

The last star to be included in the curve or spiral which started at Orion's belt is the giant red ALDEBARAN, in Taurus, the Bull, a star easily identified by its colour.   It lies almost opposite to Sirius on the other side of the belt
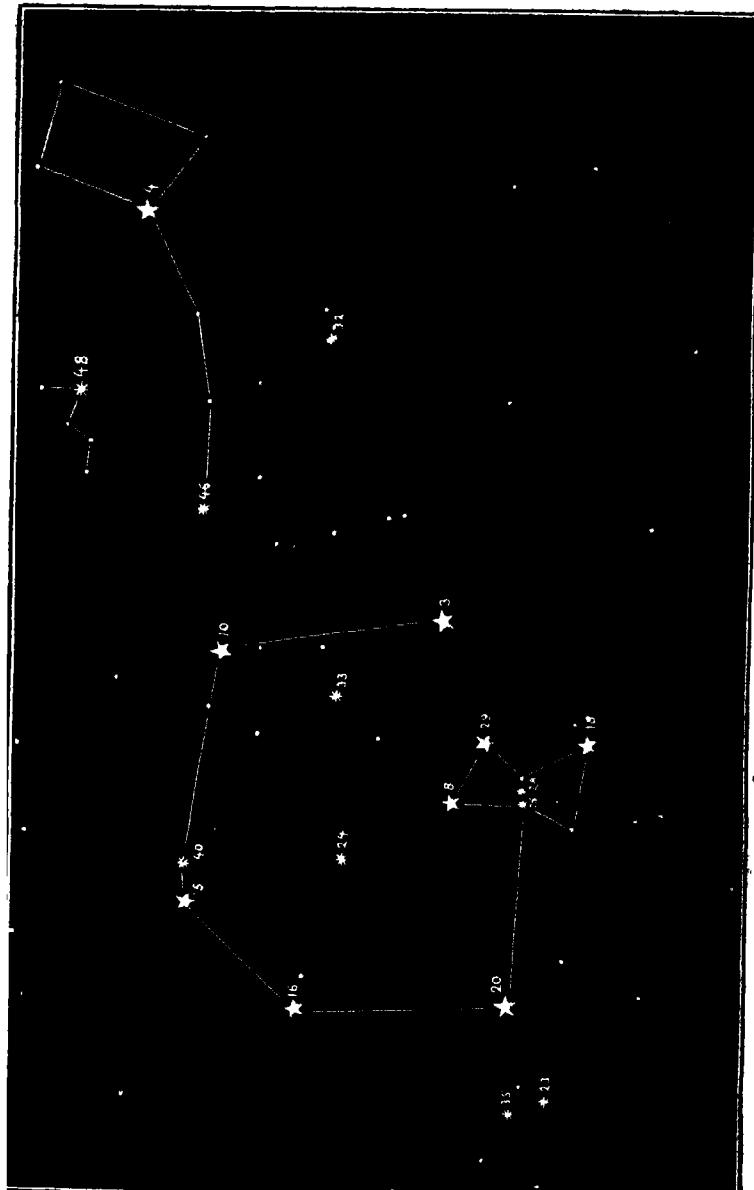
Star Diagram 2.—Orion.

3. ALDEBARAN	16. PROCYON	25. ALNITAK	33. NATH
4. ALPHERATZ	18. RIGEL	28. ANILAM	35. WEZEN
8. BETELGEUSE	20. SIRIUS	29. BELLATRIX	46. MIRFAK
10. CAPELLA	23. ADARA	32. HAMAL	48. SCHEDA
15. POLLUX	24. ALHENA		

Fig. 27.

stars.   Close to Aldebaran, in the opposite direction to Orion, is a group or open cluster of stars known as the PLEIADES, seven stars of which are just visible to the naked eye (" The Seven Sisters ").   They appear to lie in a faint patch of light no larger than the diameter of the moon, which is seen through a telescope to be a cluster of about 50,000 faint stars, known as a globular cluster.   (See Chapter 7, para. 10.)

The nine stars associated with Orion are of great importance to the navigator, since they cover a very larger area of the sky, and are all, excluding Castor, of excellent magnitude for sight-taking.   Their names are a little difficult to remember, but the following sentence may be found helpful to the beginner :

Better   **B**elong   to the   **R**oyal   **S**ociety for   **P**upil   **P**ilots
Betelgeuse **B**ellatrix   **R**igel   **S**irius   **P**rocyon **P**ollux

who   **C**annot   **C**ope   with   **A**viation.
      Castor   **C**apella   **A**ldebaran.

Or just B^2.R.S.P^2.C^2.A.

15.   In the same star diagram can be seen the Square of Pegasus, with the star ALPHERATZ at one corner, and a line of secondary stars extending from Alpheratz to the star MIRFAK, and underlining the letter " W " which is formed by the stars in the constellation Cassiopeia.   Although none of the stars in the latter are important (brightest Schedar), it serves a very useful purpose in providing a means, which is circumpolar, of locating stars which lie in the " six o'clock " area around the pole, using the same clock face with the Plough at twelve o'clock.

Star Diagram 3.   (Fig. 28).

16.   This map covers a part of the sky which is not so abundantly filled with bright stars.   The region lies between two o'clock and seven o'clock around the pole, with three important stars dominating this part of the sky. Together they form a large, almost isosceles triangle, with its apex always nearest the horizon from mid-northerly latitudes.   The sides of this triangle form useful pointers to other stars.

Starting with the brightest star in the triangle, we have VEGA, a brilliant star in the small constellation Lyra (The Lyre), forming one of the base corners. This is the most important star in this area of the sky, being of great magnitude
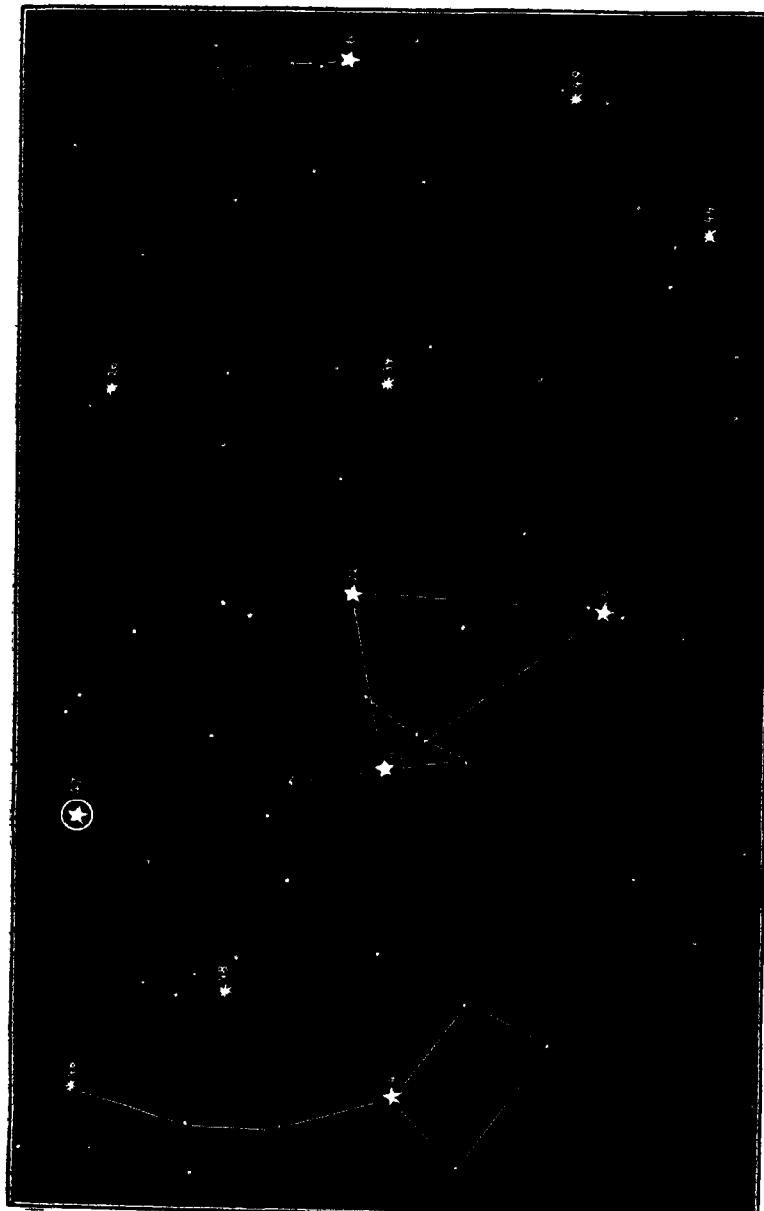
STAR DIAGRAM 3.—VEGA—DENEB—ALTAIR.

4. ALPHERATZ	22. VEGA	46. MIRFAK
5. ALTAIR	26. ALPHACCA	47. POLARIS
6. ANTARES	34. RAS ALHAGUE	48. SCHEDA
11. DENEB	44. KAUS AUSTRALIS	49. SHAULA

and good northerly declination. At the other end of the base of the triangle is DENEB, an average star which just falls into the first magnitude classification. It is the principal star in the constellation Cygnus, in which mythology depicts a swan with outstretched wings flying towards the centre of the triangle. The three small stars which are almost in line close to Deneb, and which represent the wings of the swan, can be seen in the diagram, and on a clear night they identify Deneb from Vega should the positions of the two base stars be confused. The line from one of these stars through Deneb points to the pole, as shown.

The third star, at the apex of the triangle is ALTAIR, in Aquila (The Eagle). Altair is almost as bright as Vega, and is easily identified on a clear night by two small stars which " sandwich " it, all three being in a perfect line, pointing towards Vega.

Remember that from northerly latitudes this great triangle always has its apex closest to the horizon ; thus the altitude of Vega and Deneb is always greater than that of Altair.

17. Using the sides of the triangle as pointers, many features in the sky may be located, thus : The line Vega through Deneb produced passes through Alpheratz, in Pegasus. The reverse line from Deneb produced through Vega passes close to the secondary Ras Alhague (pronounced ràs äl-hä'gwĕ), and for some distance across the equinoctial to the bright star ·ANTARES, in Scorpio (The Serpent), which never rises far above the horizon for northern observers. Finally, the line Altair—Deneb produced passes through the important star Capella.

The Planets.

18. The stars are very distant bodies of vast dimensions, many of them similar in size and character to our own particular " star," the sun. The earth is a small and insignificant body revolving around the sun, and with it are other bodies not unlike the earth, known as Planets, revolving on orbits around the sun some of which are smaller and some larger than that of the earth.

It is only by virtue of their extreme closeness to us, when compared with the distances to the stars, that they appear as bright objects in the sky. Although they are similar in appearance to the stars when seen with the naked eye, they are in every sense totally different, and do not even emit their own light ; they are visible at night only because, like our moon, they are lit up on one side by the light from the sun.

Circling with the earth around the sun on orbits of various sizes, and at vastly different orbital speeds, the planets, unlike the stars, are not fixed on the celestial sphere, but are seen to move a little each night among the constellations. Known to the early astronomers as " wandering stars," they often confuse the observer who may be searching in their vicinity for a certain star. Their positions may be found at any particular time from the air almanac, in which the S.H.A. and declination are tabulated daily. Often they are located by referring them to the constellation in which they appear to be lying, thus Jupiter on a certain night might be said to lie in the constellation of Orion. Remember, of course, that they traverse the sky nightly just like the stars, due to the earth's own rotation.

19. It is possible to define their movements more precisely than this, however, for they do not circle the sun in many different planes, thus wandering among the stars from night to night without plan. All the planets, including the earth, revolve around the sun in a flat belt only 18° wide, thus the possible positions in the sky in which planets may be found are limited to an 18° band, which crosses the southern sky in a similar manner to the equinoctial, but below it on summer nights and above it on winter nights. This band containing the paths of every planet lies on either side of the Ecliptic, a term which is fully discussed in Chapter 5.

20. Whereas starlight twinkles unsteadily because the earth's atmosphere interferes with the straight passage of such a minute point of light, the planets shine with a steady light because they have appreciable angular dimensions as seen from the earth, with sufficient light to cut through the earth's atmosphere without interference. When viewed through a powerful telescope the stars still appear as single points of light, but the planets immediately reveal a measurable diameter, showing how very much closer they are to the earth.

Their steady light is therefore one of the important characteristics to be looked for when identifying the planets. The four planets of navigational value also have slight differences in appearance which assist when picking out one from the other without resort to the air almanac.

21. VENUS, known as the morning or evening " star," is the brightest, and at times closest, of all the planets, and is ideal for sextant observation. But since it is closer to the sun, and its orbit lies within that of the earth, it can only be seen by looking into that part of the sky adjacent to the sun ; that is, a few hours before sunrise or after sunset. Its great brilliance, how-

ever, often allows sextant observations to be made in twilight well before or after the other stars and planets are visible.

22. JUPITER, the largest of all the planets, is a little less bright than Venus because it is further away from the earth. But unlike Venus, it may be seen anywhere along the ecliptic band, since its orbit is outside that of the earth. Since Venus is only in the night sky for short periods, Jupiter is far the most frequently used of the planets for navigation, often being visible for long periods of the night, such as when it lies on the opposite side of the earth to the sun.

23. MARS, which lies next to the earth on a slightly larger orbit, is of special interest to astronomers, because its illuminated face comes closer to the earth than that of any other planet, and therefore calls for special study. Though Venus passes closer to the earth at certain times, it lies between us and the sun, and we only see the dark side, or a narrow crescent like the first or last quarter of the moon. Mars is easily recognised by its red colouring, which immediately distinguishes it from most stars.

24. SATURN, with an orbit larger even than Jupiter, is the most distant planet used for navigation, and is on the average the least brilliant of the four used for navigation. But it is brighter than many first magnitude stars, and should not present as much difficulty as Polaris, for example, which is often unsuitable for sighting if there is a slight haze or high cloud obscuring perfect vision. The peculiar formations of dust particles around Saturn are well known as the Rings of Saturn, but they are not visible without the aid of a small telescope.

25. It should be noted that all the planets vary their magnitudes according to their distance from the earth, and in the case of Venus and Mercury (the latter is not suitable for navigation), according to their phase. Thus it is not a good method to remember them by their brilliance alone, since in a few weeks time this may well have altered considerably.

The greatest care should be taken to avoid mistaking a planet for one of the stars in a nearby constellation on which a sight is required. The variable positions of the planets can sometimes be very confusing, particularly when the navigator has not studied the sky for some time and is uncertain of their location. Their steady light, contrasting with the twinkling of the stars, is a sure warning against this common mistake.

Planispheres.

26.   A planisphere is any form of adjustable star map, and may be used to identify the stars and planets at any time of the night or year.   It is not an instrument from which accurate measurement may be made ; its purpose is only to present a picture of the sky that is sufficiently faithful to enable given stars to be recognised easily and quickly.

THE PHILIPS' PLANISPHERE.

27.   This is a simple form of planisphere not specifically produced for
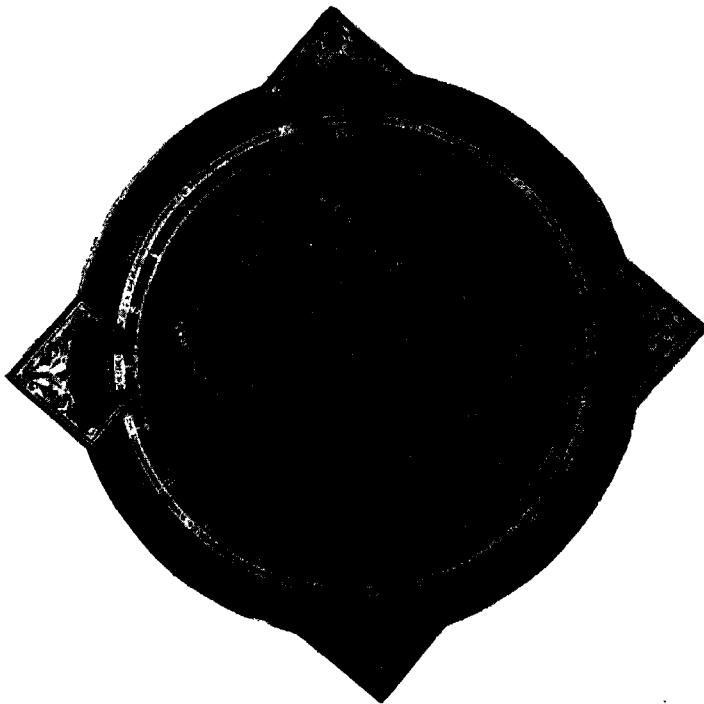
Courtesy of Geo. Philip & Son, Ltd.

Fig. 29.

astro-navigators, and therefore containing a certain amount of unnecessary, though interesting, information.

The planisphere consists of a circular disc bearing a map of the stars, revolving inside a cardboard frame which has an oval opening. The opening is such that when the disc is correctly rotated for date and time of observation, only those stars in the sky at that time are visible, and they appear in their correct relative positions with respect to the horizon, represented by the edge of the opening. (See Fig. 29). Different planispheres must be made for different latitudes, although each may be used on a fairly wide latitude range.

To set the planisphere, it is only necessary to put the desired G.M.T. of observation on the time scale, opposite to the correct date on the outer scale. The planisphere should then be held over the head and orientated in the same way as a map, to bring the Pole Star on the planisphere opposite the direction of the Pole Star in the sky. The observer may now face any direction and bring the planisphere down a little in front of him, provided the Pole Star on the planisphere remains pointing to the north.

THE FLOWER PLANISPHERE (Fig. 30b)

28. This excellent planisphere has been designed for use in astro-navigation, and therefore contains only that information which is of special value.

The star map is drawn on a circular rotatable disc, over which may be fitted any one of a series of celluloid overlays, each having an opening that corresponds to a stated latitude band. Circles of altitude and curves of azimuth have been drawn on the celluloid which greatly assist star identification (Fig. 30a).

To set the planisphere, first select the correct celluloid overlay according to the latitude, and insert it into the metal grooves of the planisphere in such a way that :

(*a*). The white Index Line lies exactly between the two black lines.

(*b*). The circle of Altitude equal to the latitude lies exactly over the Pole Star. (Alt. of Pole Star=Obs. Lat. Chap. 2, para. 30).

It has already been shown that the Hour Angle of the First Point of Aries is the usual method of locating the celestial sphere relative to the earth. Enter the Air Almanac, therefore, on the correct date page, and against the G.M.T. extract the G.H.A.Υ ; apply the approximate longitude ($+$ if east, $-$ if west) and set this value on the planisphere opposite the L.H.A.Υ index mark.

The Flower Planisphere may also be used for locating the Planets. The S.H.A. and Declination are obtained from the correct date page of the Air Almanac, and the planet plotted on the star disc using these values as co-ordinates, according to the instructions on the back of the planisphere.

The celluloid overlay is first removed, so that the planet can be plotted with a grease pencil on the star disc. The S.H.A. planet is subtracted from 360° and this value set opposite the L.H.A. Υ index mark.

On the special scale on the back of the instrument the Declination is measured off with dividers, and the distance plotted in from the edge of the star disc (opposite the L.H.A. Υ mark) towards the Pole Star. This will give the position of the planet for the particular night in question. Since the planets move among the stars, they will need re-plotting after several nights have passed. (See para. 18.)

Note—the quantity 360°—S.H.A. is known as the Right Ascension of the body, and may be defined as the angular measure of the body's meridian EAST of the meridian of Υ. It is usually measured in time, whereas S.H.A. is measured westwards in arc. (See also Chap. 5, para. 17.)

The mean R.A. and S.H.A. of the planets is tabulated daily in the Air Almanac.
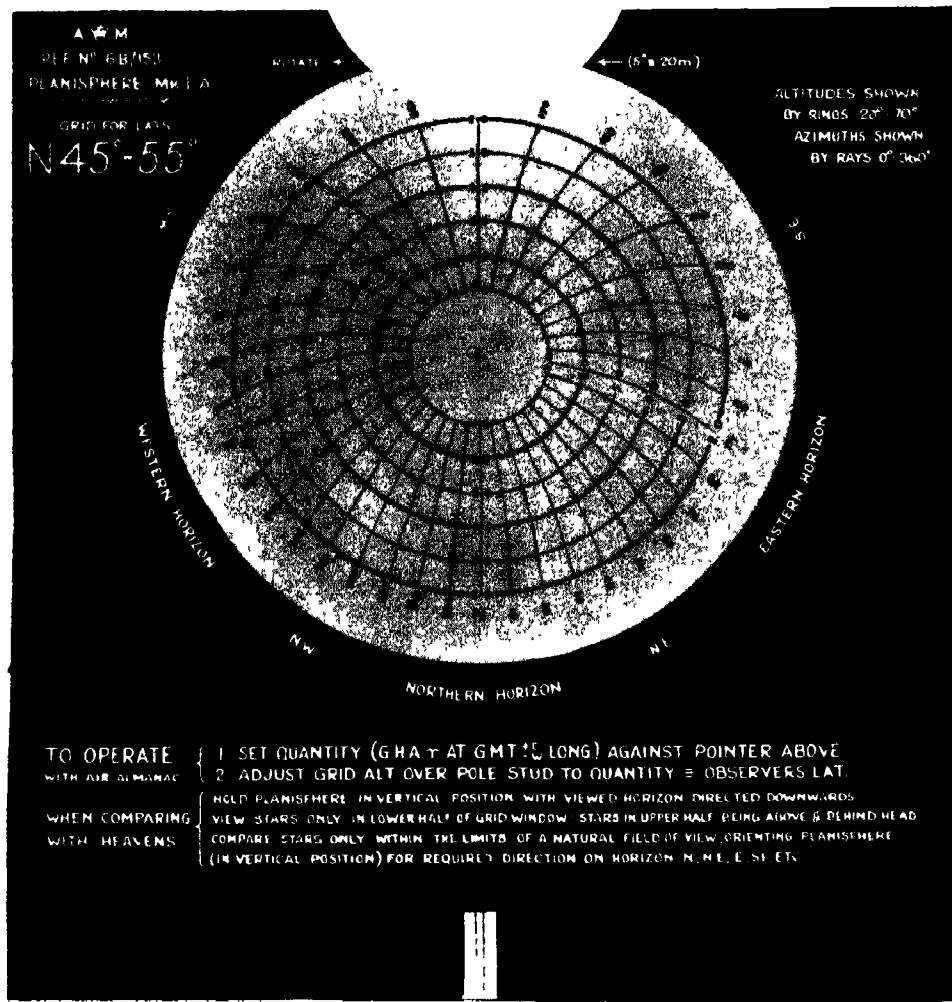
THE CELLULOID OVERLAY FOR A SELECTED LATITUDE BAND WHICH IS PLACED OVER THE STAR MAP OF THE FLOWER PLANISPHERE.

Fig. 30a.
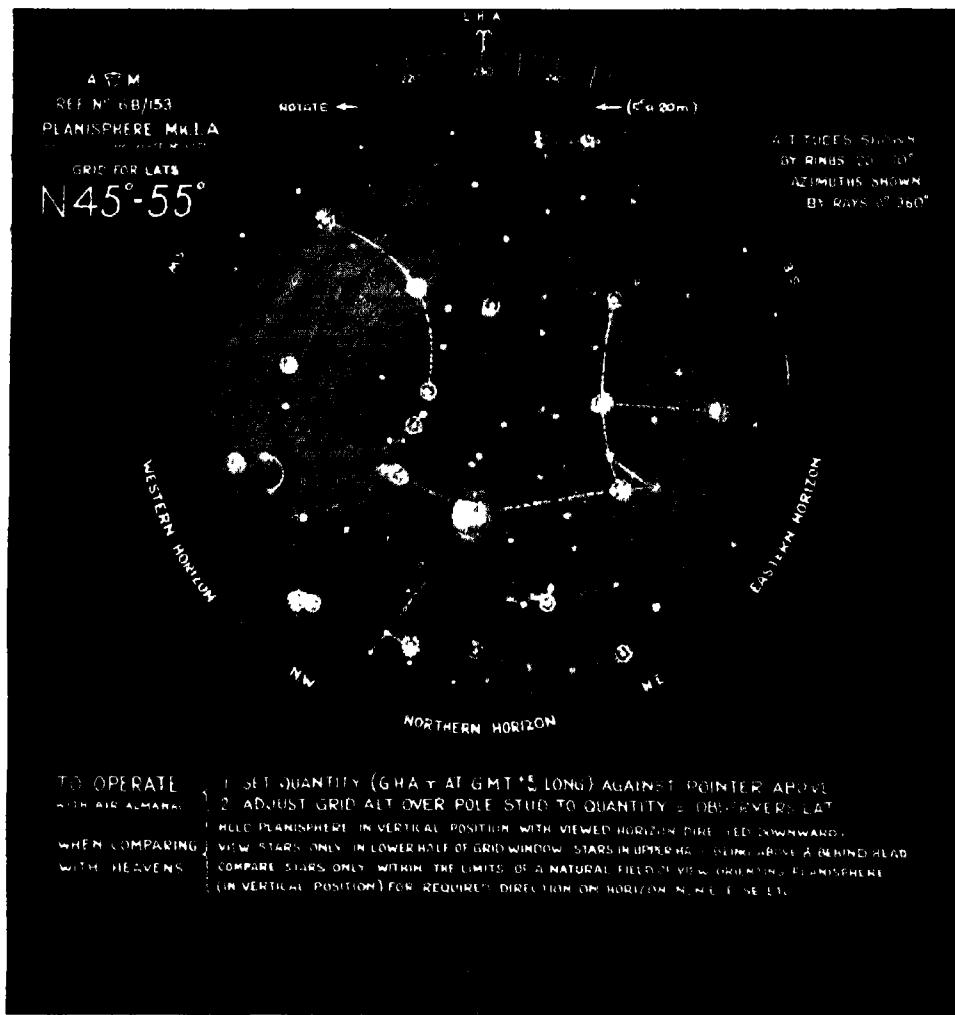
THE FLOWER PLANISPHERE WITH OVERLAY FITTED.

Fig. 30b.

CHAPTER FOUR.

PRACTICAL WORK IN THE AIR.

1. Successful sextant observations depend on a very close co-operation between pilot and navigator, and it would be little exaggeration to say that over 75 per cent. of the accuracy of results depends on the pilot.

It is essential that the procedure in the air should be such that the whole process is carried out under the most ideal possible conditions. It is necessary to evolve a detailed routine for each person concerned, so that the drill is always the same, and everyone appreciates the importance of the part he is playing in producing the final results quickly and accurately. The navigator should consider not only his own needs, but also the best moment to call the other members of the crew away from their respective duties. For example, a navigator who asks his pilot to steady the machine for an astro sight when he is flying through heavy " Flak " is liable to come to grief either on the spot, or afterwards at the hand of his pilot seeking retribution !

2. Having made up his mind to take sights, the navigator should first inform the pilot of his intention, and position himself in the dome or at the point of observation. If available, a third member of the crew may act as timekeeper, and also to liase between navigator and pilot. The following is a suggested routine that could be adapted to almost all conditions :—

    (*a*).   Navigator brandishes sextant before pilot, who nods, and commences to trim aircraft carefully.

    (*b*).   Navigator takes station in dome, and timekeeper beside the pilot, with astro watch and pencil and pad.

    (*c*).   Navigator presets sextant for observation, nods his head to timekeeper, who raises his thumb in front of pilot. Pilot commences to concentrate.

    (*d*).   Navigator, with sextant to his eye, raises his thumb and commences to " shoot " ; timekeeper notes watch reading.

    (*e*).   Navigator finishes " shooting," raises thumb again to timekeeper, who notes watch reading and makes a cancellation sign in front of pilot, so that he can relax. Navigator notes star's name and altitude on side of sextant.

    (*f*)   Repeat (*a*)—(*f*) for other stars as necessary.

The drill may be varied according to requirements and layout of aircraft, and if telephone inter-communication is efficient this may be used to replace visual signals.   Where possible, the timekeeper may take the sextant observations himself.   This arrangement takes a great deal of responsibility off the navigator, and he will not be upset in his work by having to leave the navigation table.   Needless to say, this member of the crew must be proficient in handling the sextant, and likewise the navigator must have faith in his observations if the scheme is to be a success.

Analysis of Sight Errors.

3.   If it were possible to fly an aircraft at an exactly constant course and airspeed during the period of a sight, then the resulting position line, other things being equal, should be accurate to within two or three miles.   Unfortunately, these ideal conditions cannot exist, there being three factors collectively doing harm to the equilibrium of the aircraft and therefore its suitability as a sighting platform.

> *Factor   I.*   Unsteadiness due to meteorological conditions such as up or down currents and general " bumpiness."
>
> *Factor   II.*   Human failings of the pilot in his ability to fly the aircraft within fine limits of course and airspeed.
>
> *Factor   III.*   Inherent tendency of all aircraft to " weave " a path through the air, rather than to fly in perfect equilibrium.

4.   Factor I needs little explanation.   What is commonly called " bumpiness " will sometimes make astro work impossible, while air currents of various kinds may cause hidden but nevertheless important variations in the smooth passage of the aircraft through the air.   It may be controlled to a limited extent by corrective action on the part of the pilot.   Fortunately, "bumpiness" is seldom very severe at night, and should not often prove a real handicap to good sighting.

5.   Factor II is one that can naturally be reduced by skilful flying and concentration on the part of the pilot.   It is important that he should understand the effects of inaccurate flying on sextant readings, and it is part of the navigator's duties to discuss such matters with him, with a view to reducing errors to a minimum.   It is essential that he should grasp the following points:

Suppose the navigator is sighting on a star ahead or astern of the aircraft. Then any slight increase in airspeed will cause an acceleration of the aircraft,

and the inertia of the bubble chamber liquid will cause it to lag and therefore throw the bubble, which is lighter, to the front of the chamber. The navigator tilts his sextant in order to keep the bubble in the centre, and thus the altitude must be adjusted to keep the heavenly body on the bubble.

Thus, alteration in the aircraft's airspeed will throw a sextant observation out when it is being made in the fore and aft line of the aircraft.

If the pilot varies his course, however, when the navigator is taking a fore and aft sight, the only effect will be to throw the bubble to one side of the chamber, which may be corrected by tilting the sextant to one side, without the altitude being affected.

On the other hand, an observation made on the beam will be affected mostly by change in course. If the pilot wanders off course, then there must be a slight sideways force on the aircraft, and since the sextant is athwartships, this will affect the altitude, as did change in airspeed on a fore and aft observation. Change in airspeed in this case would only cause sideways movement of the bubble.

Naturally observations made in any direction lying between the beam and fore and aft will be affected by both course and airspeed errors, and it will be necessary for the pilot to concentrate equally on both factors if an accurate sight is to result.

On receiving the signal that the navigator is starting to observe, the pilot should note the airspeed and the course, and try to keep those readings. If, for instance, the airspeed creeps up 3 m.p.h., or the aircraft yaws 2°, he should not be content to hold steady on the new readings, but try to coax them back to their original figures. If he can manage to bring the airspeed and course back to their original readings at the end of the period of observation, any departures which he may have made during the sight will probably cancel out.

6. **Factor III.** Experiment has proved that aircraft do not fly a perfectly smooth and steady course through the air, even when the controls are manipulated almost faultlessly (such as with an automatic pilot). In reality they " weave " a path through the air—they have periods of slight yaw and climb or dive, resulting in acceleration and deceleration forces which will influence a bubble sextant.

The result produced by this cause alone is that the bubble altitude rises and falls continuously by amounts varying between $\pm 30'$ and $\pm 100'$. This may take place over irregular periods of between 10 and 90 seconds. In some cases a short period variation may be superimposed on a longer one.
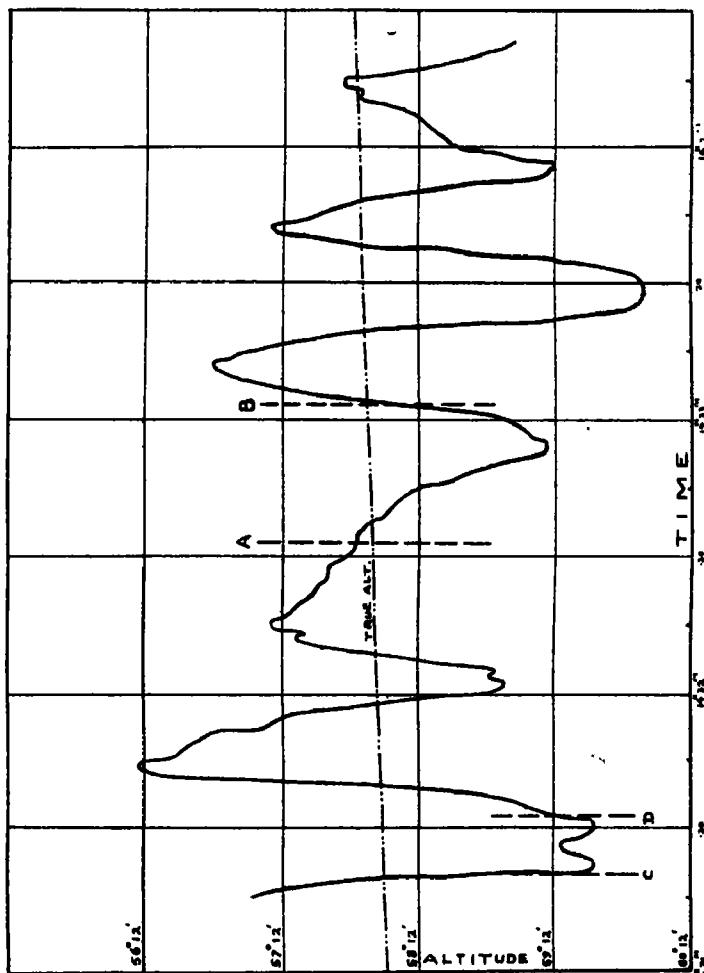
Fig. 31.

Such a situation may best be illustrated by a graph showing the altitude readings of the bubble recorded continuously over a period of minutes. (See Fig. 31.)   The dotted centre line is the line of correct altitude, or " nil error," and movement of the curve above or below this line gives positive or negative errors respectively in altitude reading, at the time shown along the scale of seconds.

It is interesting that all aircraft of a particular type have nearly the same bubble " behaviour curve " while the curve for various types of aircraft is totally different.

It is exceedingly unwise, when using a multiple shot sextant, to take the run of sights in a very short period, such as 30 seconds.   In Fig. 31, suppose thé period of such a run occurred between A and B, it will be seen that the averaged answer will bear an error of some 25 minutes of arc.

It is equally wrong to be tempted to wait until the bubble appears quite steady before commencing the sight, and then to rush in the necessary run of shots before the altitude begins to change again.   Such a moment of apparent steadiness of the bubble is in reality almost certainly a period of Maximum error, such as between C and D in the diagram, when the altitude has steadied at the top of a rise before commencing to fall again, or vice versa. The moment of correct altitude is almost impossible to predict, as the curve invariably rushes straight past it, just as the pilot, trying to fly at 160 m.p.h., probably oscillates between 157 and 163.

It must be remembered, however, that the errors of " weaving " are not due to the pilot, and cannot be corrected by him.   Moments of nil error, therefore, are invariably brief, and the most effective way to avoid getting large errors is to spread the run of sights out evenly over a period that will depend on the type of bubble " behaviour " curve that is under consideration. As a general rule, however, two minutes is usually the most effective length of sight ; in this period, taking an even run of as many shots as possible, plus and minus errors should be well mixed to give an averaged answer reasonably close to the correct altitude.

In certain aircraft the period of oscillation is a very long one, and it is possible to make an exact coincidence at any given moment.   In these circumstances, the observer is tempted to think that conditions are good, and to dash off a quick series of shots.   He should do just the opposite—observe very deliberately at 5 or 6 shots per minute for at least two and preferably three minutes.

Summary.

7.   Advice to Navigators :—
  (*a*).   Always warn the pilot when you are going to take sights.
  (*b*).   If using a Mk. IX R.A.F. Sextant, a run of at least two and preferably three sets of six should be taken consecutively, writing down the altitude and clearing the totalisor between each, afterwards averaging out all three. If the result of one six appears wide in comparison with the other two, do not throw it out ; average all three.
  (*c*).   Never hurry a sight if the bubble appears well settled for a good period. Continue to observe at the normal rate with a minimum of three sets of six.
  (*d*).   If the air is bumpy, remember conditions may be better a thousand feet above or below—probably above.

8.   Advice to Pilots :—
  (*a*).   Trim the aircraft to fly as nearly as possible " hands off."
  (*b*).   Fly by instruments, or by " George " if it is fitted.
  (*c*).   If you wander slightly off course or airspeed, try and coax the machine back again rather than settling at the new reading.
  (*d*).   Good observations may be made on a shallow dive or climb, PROVIDED course and airspeed are kept constant.
  (*e*).   Notice the direction in which the observer is shooting, and concentrate on the relative instruments, as explained in para. 5.

★

Z Correction.

9.   A new factor has recently been determined which has a measurable influence on a sextant bubble chamber. The practical application of the correction is far less complicated than might be supposed by glancing at the tables, since most of the work is carried out before flight, and only a section of the table is needed in the air.

   The correction is divided into two parts, which are in no way connected, but which are conveniently tabulated under the one heading.

F

10. It was discovered by a Frenchman named Gaspard Coriolis that the earth's rotation had a marked influence on the true path of a moving body travelling in an otherwise straight line.

Consider Fig. 32. The earth rotates from west to east at an equatorial speed of 900 miles per hour, completing one revolution in approximately 24 hours. A point at, say, 52°North will have a smaller circle to complete in the same period, and will therefore have the slower speed of about 600 miles per hour.
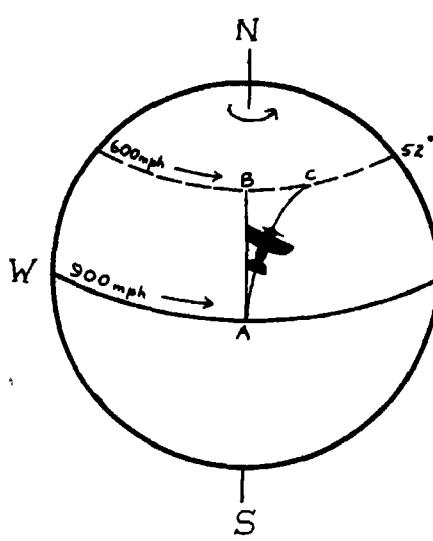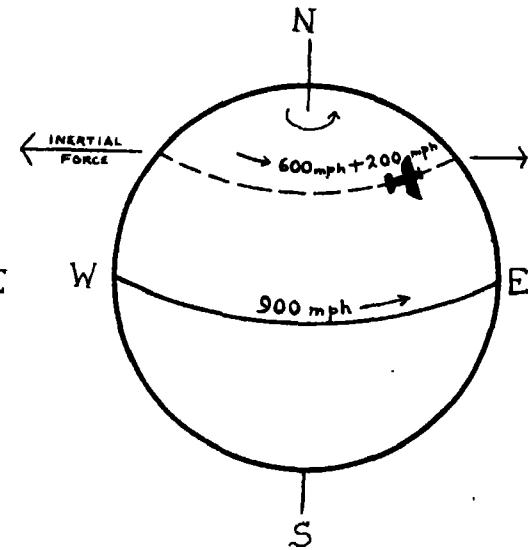
Fig. 32.   Fig. 33.

Suppose an aircraft leaves point A on the equator, and flies along a track to point B, assuming the wind velocity to be nil. At A, the earth—and therefore the aircraft—will have an easterly speed of 900 miles per hour, but as the aircraft flies north, the surface speed of the earth decreases. The aircraft, retaining the easterly speed imparted to it at A, will gradually possess a slightly higher relative velocity to the east, that is, its path will deviate to starboard in the direction of point C.

Similarly, an aircraft flying South from point B will have an easterly speed of 600 miles per hour, but as it changes latitude the earth's surface

speed to the east increases and gives the aircraft a relatively curved path to the west—again to Starboard.

11. Now take the case of an aircraft flying east or west at a constant latitude of 52°North, as in Fig. 33.

Any body at rest is being acted upon by two forces in opposite directions ; the force of gravity, and the force of inertia, the latter tending to throw the body away from the earth due to its speed of rotation.

If an aircraft commences to fly at any considerable speed in an easterly direction, the inertia force is increased, since the aircraft is now travelling at the earth's surface speed plus its own speed. Since the direction of this force is at right angles to the earth's axis and not from its centre, the aircraft will be deflected towards the equator—to starboard—thus carrying it further from the axis.

An aircraft travelling in a westerly direction will have a smaller speed than the surface speed of the earth, with the result that the centrifugal force is diminished and the aircraft will tend to move closer to the axis—towards the pole—or again to starboard.

12. From the above four cases of the Coriolis effect it will be seen that no matter what the direction of flight an aircraft has a tendency to deviate to the right in the northern hemisphere, by an amount directly proportional to the latitude. On the equator the effect will not exist, while in the southern hemisphere the deviation will be to the left.

Since the force acting on the aircraft will also take effect on any movable part within it, travelling at the same speed, the sextant bubble liquid will always tend to be thrown to the right of the aircraft no matter what the heading of the aircraft may be. Thus the bubble, being lighter, is thrown to the left by the liquid, and the sextant, if used in the fore and aft line of the aircraft, must be tilted by some 4' to keep the bubble central. This will not influence the altitude obtained from a fore and aft sight, but it will produce a maximum error on a sight taken at right angles to the heading of the aircraft, since here the sextant must be tilted backwards or forwards to centralise the bubble, thus giving a false datum from which to measure the altitude.

Coriolis effect, therefore, is nil when the relative bearing between the aircraft's heading and the heavenly body is 0° or 180°, and a maximum when the relative bearing is 90° or 270°.

The correction for Coriolis error is made in the first section of Table I in the Air Almanac Z Correction Table (see Appendix A, Table 13). The

required value is extracted against the D.R. Latitude and the Airspeed. (Change of Airspeed will cause a change in the centrifugal force and thus the value of Coriolis.)   Airspeed is used rather than groundspeed, since the value is more readily calculated before flight, and the difference between them produces a very small change in the value extracted from the table.

13.   The second half of Table I headed " Wander degrees per minute " allows for the gradual change of course that takes place when an aircraft is steered by a gyro-compass which is slowly precessing.

The amount of this gyro-precession will vary with different aircraft and even with course, but a mean value may be found by flying steady courses by gyro-compass for about 20 minutes each and checking the change in reading of the magnetic compass, remembering to apply the respective Variation to the readings for the start and the end of the run.

14.   Since precession of the gyro produces an error in course, the maximum effect on the sextant bubble will be felt when the sextant is held athwartships.   Thus the two sections of Table I have a maximum value on the beam, and are nil when sighting fore and aft.

15.   The combined quantities from the Coriolis and Wander sections of Table I are then computed in Table II against the relative bearing value, which is tabulated as 180° Port or Starboard.   In practice only one column of Table II is required in the air, and this may be extracted and entered in the space provided on the right-hand page of the Z Correction pages.   (Appendix A, Table 13).

Procedure.

16.   *BEFORE FLIGHT.*

(a).   Extract from Table I first value (Coriolis) by reading approximate latitude of the flight against estimated True Air Speed.   Apply +sign if northerly latitude.

(b)..   Extract from Table I second value (Wander) obtained by reading predetermined gyro-wander against True Air Speed.   Apply + sign if wander is to port.

(c).   Combine these two values algebraically to obtain argument for Table II.

(d).   Enter this value in the top space of the special blank column provided in the Z Correction example (Table 13 of Appendix

A), and enter the respective signs at the bottom of each relative bearing column. Thus if argument from Table I is plus 6, insert plus 6 in the top space, and a minus sign at the bottom of the port column and a plus sign at the bottom of the starboard column.

(e). Extract the respective column from Table II (in this case 6′) and enter the values in the space provided.

17. *DURING FLIGHT.*

(a). After observing the heavenly body, estimate the relative bearing. This may be simplified by a scale on the edge of the astro dome or on the sextant suspension disc.

(b). In the prepared table in the almanac (para. 16d) read off the value of Z correction opposite the relative bearing value, and apply the sign at the bottom of the respective relative bearing column.

(c). Apply Z Correction to the Sextant Altitude.

18. It is not suggested that the navigator should apply Z Correction before he has acquired a certain degree of skill in astro-navigation ; the value is often small and therefore a matter of refinement when he feels himself capable of dealing with the additional correction. Let him first bring his sighting errors within such limits that the need for Z Correction will make itself felt.

★

The Employment of Astro Position Lines.

TWO AND THREE STAR FIXES.

19. Consecutive observations of two stars, when plotted and transferred to allow for the aircraft's run along track between the sights, will give a FIX. For increased accuracy, a third star may be observed, giving a "cocked hat" of three position lines, the first two being transferred to the time of the third. An example of the plotting required is shown in Fig. 34, in which a successful small cocked hat has been obtained ; the size of the cocked hat, broadly speaking, is a guide to the accuracy of the answer.

THREE STAR FIX.

Fig. 34.

DEPARTURE FROM
LIZARD HEAD AT
09.55 G.M.T.

10.12

W.T. RUNNING FIX
BY THREE
LOOP BEARINGS.

10.30

10.43

CIVIL
BROADCAST
STATION.

FRANCE

MEAN OF SIX W.T.
LOOP BEARINGS
TAKEN AT ONE
MINUTE INTERVALS.

12.15

SUN   12 06

12.15

COMBINED FIX BY
LOOP BEARING
AND SUN POSITION
LINE.

ALTER COURSE
FOR
ESTACA PT

SUN

12.58

SUN POSITION LINE
TO PROVIDE E.T.A.
AT ESTACA PT.

ESTACA POINT

SPAIN
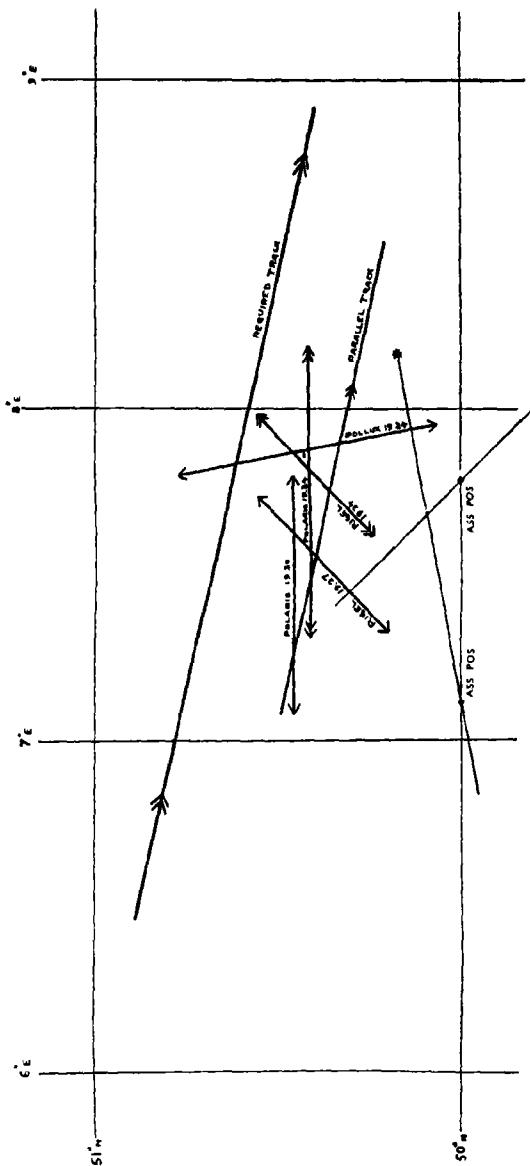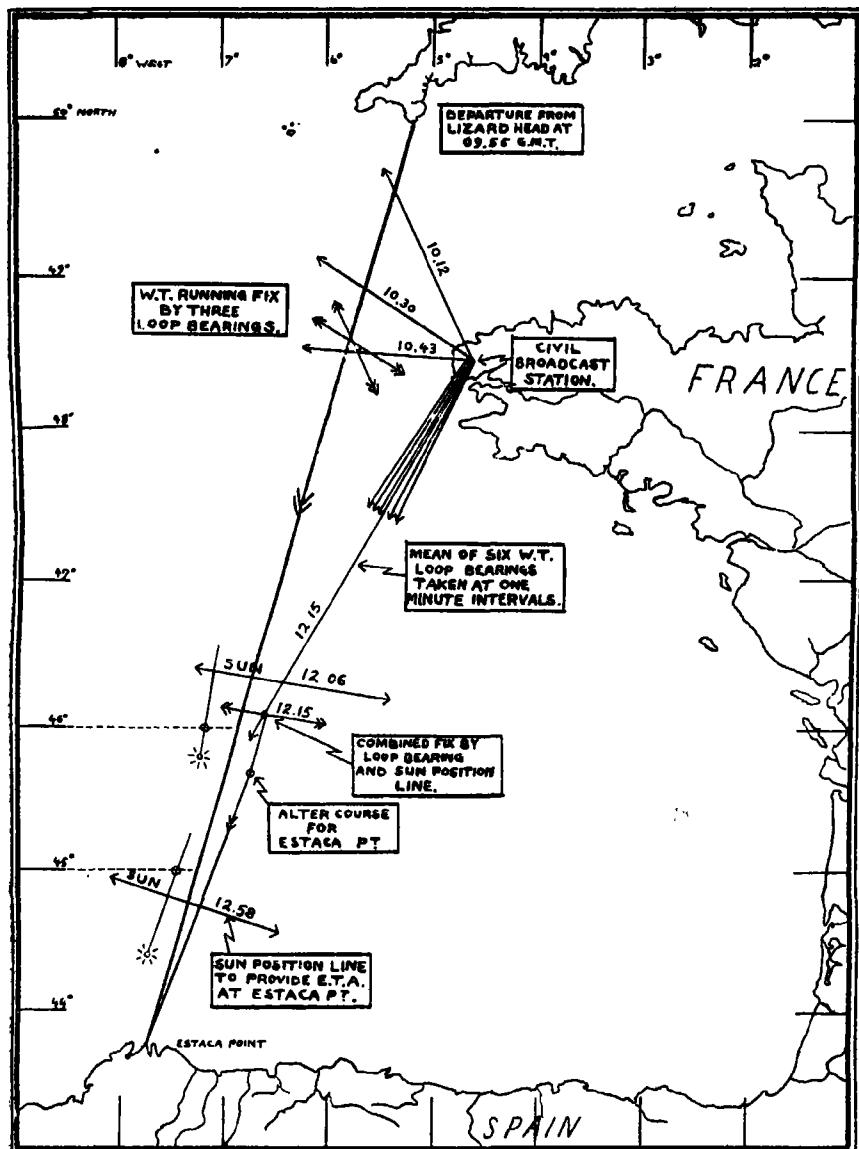
Fig. 35.

Although the expression " Three Star Fix " has been used, Fixes may equally well be obtained by combining position lines from any of the heavenly bodies, such as Sun, Moon or Planets, or even a composite fix of Astro and W/T bearings. For example, an observer flying across the Bay of Biscay (Fig. 35) en route to Lisbon, leaves Lizard Head for Estaca Point in Spain, during which time he has successfully combined astro observations with wireless loop bearings, finally checking his E.T.A. at Estaca Point by a sun position line.

CHECKING TRACK BY SINGLE POSITION LINE.

20. A heavenly body whose azimuth differs by 90° from the track of an aircraft—that is, a star which appears on the aircraft's beam, will give a position line that is approximately parallel to the track. This may be of great value to a navigator who is anxious to ascertain his track line without having time to obtain a fix (Fig. 36).
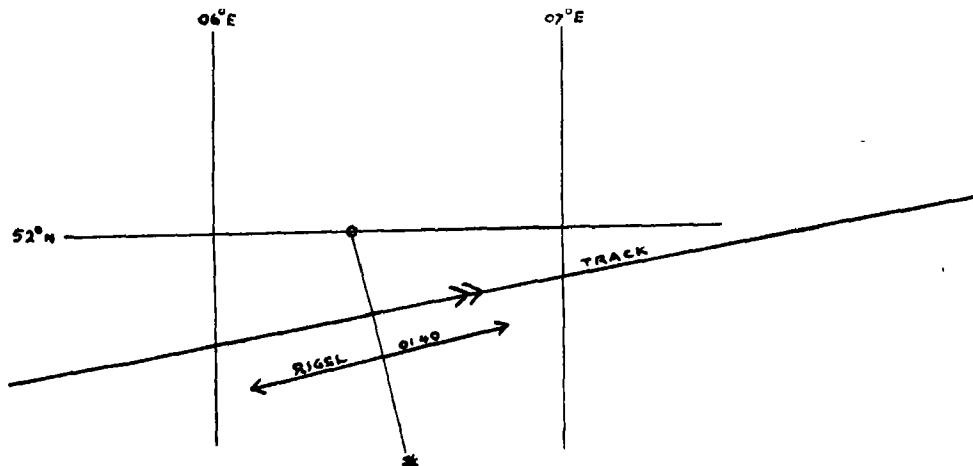
Fig. 36.

CHECKING GROUND SPEED BY SINGLE POSITION LINE.

21. A heavenly body whose azimuth lies within about 10 degrees of the aircraft's track will give a position line that may be used to determine the aircraft's ground speed since the last check on position (Fig. 37). A period

of at least thirty minutes must be allowed, however, between the starting position and the position line, if an accurate ground speed is to be obtained.

11°E   12°E

50°N -

49°N -
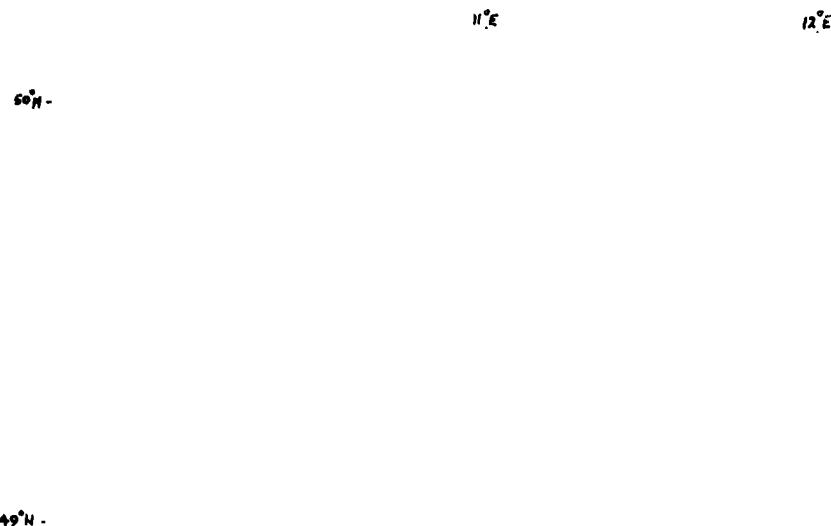
Fig. 37.

THE POLARIS SIGHT.

22.   It is possible to work out a Polaris sight in a very short time, and the utmost value should therefore be obtained from this navigational aid in order to keep down the total amount of work. A navigator having the good fortune to be flying due north or south has available a quick and accurate check on his ground speed, and similarly if he is flying east or west, there is little excuse for not knowing his track made good when Polaris is visible.

In Fig. 38, an observer flying from Lowestoft to Berlin without using astro will set course from Lowestoft, and on E.T.A. Dutch coast he will naturally attempt to map read in the region of Point A, that is, along the track he hopes he has made good.

The astro-navigator, however, with a sequence of Polaris sights at intervals, will attempt to map read in the region of Point B, because his Polaris sights have told him that he is making good LB and not LA as required. Further-
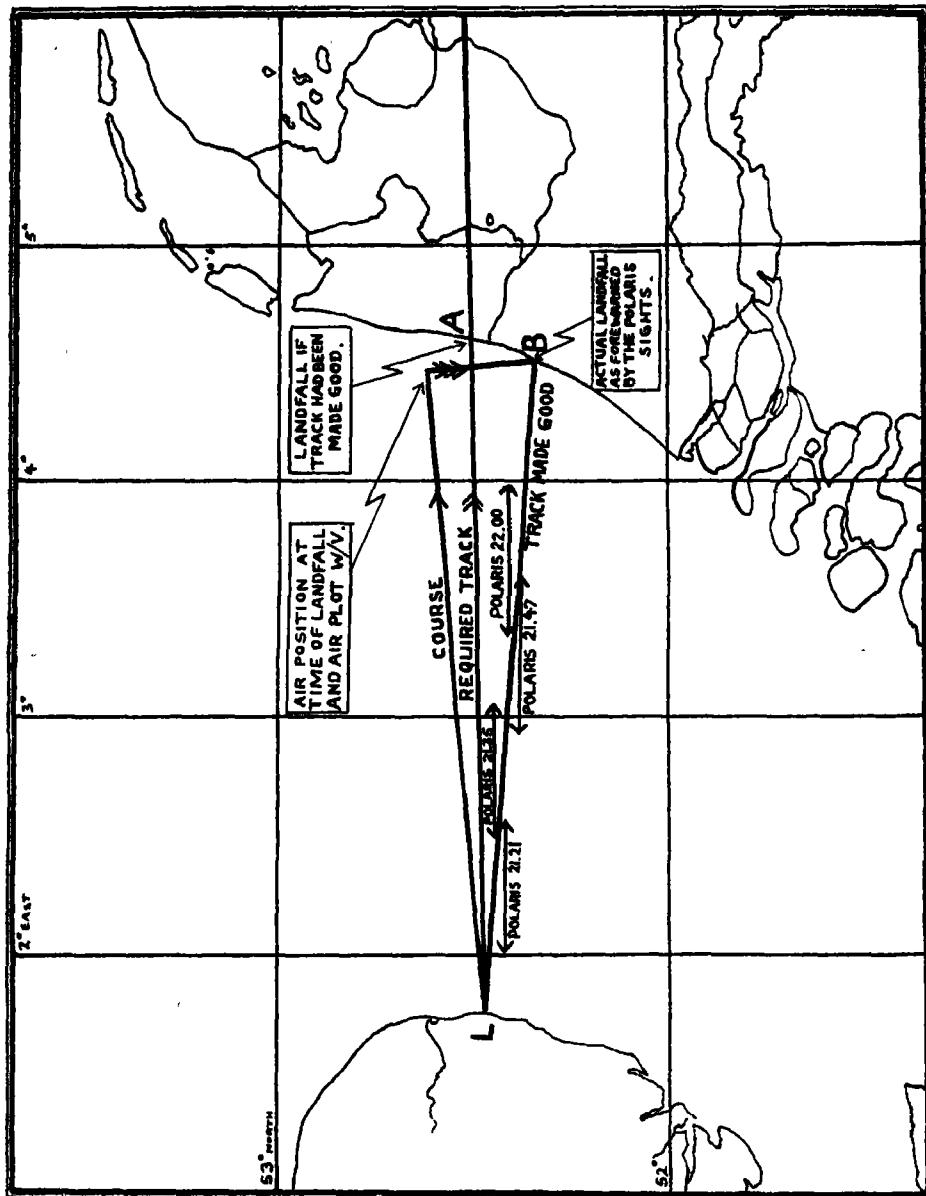
Fig. 38.

more, in the event of the coastline being obscured, he can take sights on a fore or aft star and transfer his last Polaris sight to get a fix. The first navigator will probably fail to pin-point himself since he is studying the wrong section of his map, and he is liable to continue with a steadily increasing D.R. error. The astro-navigator, whether or not he obtains his pin-point— and he certainly has the best chance of doing so—will be aware of his drift off track and take action accordingly.

Polaris is not an easy star to observe, being of relatively low magnitude. It is essential to obtain a great deal of practice in this form of sight, and to use it on every possible occasion. The time taken to work out a two or three star fix may be reduced by the inclusion of Polaris.

COMBINATION FIXES.

23. It often happens that less experienced navigators do not feel confident in their ability to take a three star fix in the available time, and allow this lack of self-confidence to influence their whole attitude towards astro.

It is essential that a start should be made with single selected astro sights such as fall under the headings of paragraphs 20–22 above, or single astro position lines combined with one or more position lines from some other source. This choice will naturally depend on the circumstances, but the following examples will illustrate the point, and show how varied are the possibilities open to a navigator who watches for such opportunities to check his position.

24 (*a*). W/T Loop Bearings.

   (*b*). W/T Bearings requested from a ground station.

   (*c*). Visual Bearings of Lighthouses or known landmarks such as mountain peaks, peninsulas or estuaries (often visible at night by moonlight).

   (*d*). Straight coastlines, rivers or railways. These may be used instantaneously as positive position lines with nil error, provided there is only one such straight section in the area.

      The Dutch coast is very straight, and when it is crossed without a pin-point being obtained, then an astro position line may be plotted to cut it at a suitable angle. Coastlines can, strangely enough, be transferred to allow for the aircraft's run along track, just like any other position line.
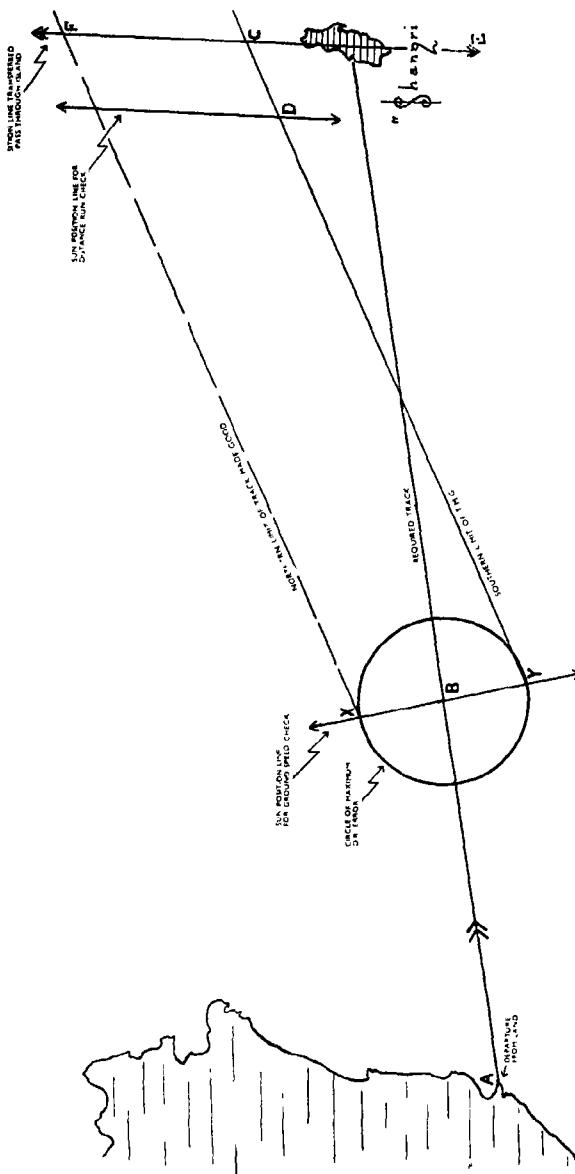
LOCATING AN ISLAND BY SINGLE POSITION LINES.

Note.—The distance AB has been reduced in the diagram.

Fig. 39.

LOCATING A FIXED POINT BY SINGLE POSITION LINES.

25.   It is interesting to study a slightly more complex problem in the application of position lines and to appreciate the less obvious methods of applying them to navigation.

Here is the situation, illustrated by Fig. 39. An aircraft leaves the coast-line at A, and proceeds to fly to an island Shangri-La, some 600 miles distant. It is imperative that the aircraft should reach its destination, without wireless assistance, the whole trip being in daylight with unreliable forecast winds. The navigator proceeds as follows.

26.   When within approximately one hour of E.T.A., he obtains and plots a sun sight, which cuts his required track at B. Using this point, he obtains a fairly reliable ground speed from the distance and time since leaving point A.

With centre B and radius equal to his estimated maximum possible D.R. error, he draws a circle. At the time of the sun sight, the aircraft must have been somewhere on the section XY of the position line.

From one end, Y, of the position line XY he draws in a track line YC to the opposite side of the island. If he has a good petrol reserve point C may be further north of the island as a precaution.

27.   The pilot is now given a course to steer such that the aircraft will, as far as possible, make good a track parallel to YC. Fifteen minutes before E.T.A. point C, the observer takes a second sun sight with special care, plots it, and transfers it to pass through the island ; he immediately measures DC, and instructs the pilot to continue on course for the time required since the second sun sight to make good this distance at the ground speed found at point B or, if he has time, the ground speed between Y and D. At the end of the required time the aircraft turns and flies a course to make good the track CE until the island is seen.

Notes.

28.   Since the size of the circle XY was made such that the aircraft .must lie within it, by taking the most southerly possible position of the aircraft at that time, and drawing a track to the north of the island, no matter where the aircraft actually was within the maximum error circle, it is certain to end up to the north of Shangri-La.   Thus if it had been at X the track made good

would have been XF, and the distance to fly down the position line FE would have been greater.

29. Provided the D.R. Error Circle is not under-estimated, the maximum error on sighting the island should not exceed the last astro sight error, since any ground speed error will have little effect over the short period between D and C. Under average conditions the sight error should not exceed the visibility distance, thus the island must come into view sooner or later. Unfortunately an E.T.A. cannot be given, since the aircraft may have turned down the position line anywhere between F and C.

It is therefore absolutely essential to ensure that the aircraft's track, parallel to YC, does actually take the machine north of the island under all possible conditions.

PRE-COMPUTATION.

30. Unless a flight is made up of long legs such as in Fig. 35, it is not always easy for the navigator to make full sight calculations in addition to his other tasks. It is helpful, therefore, to understand the method whereby sights may be pre-computed for certain points along the route where they are most likely to be of value. The modern tendency to keep to an exact schedule of departure and arrival favours the navigator who wishes to make astro-computations before flight.

31. The navigator must determine, by the most accurate possible means, the time at which the aircraft will reach the approximate area in which each sight is required. The whole computation is then carried out on the ground for a selected star, and the calculated altitude and azimuth obtained for a suitable assumed position.

In the air, the observation of the star is commenced just prior to the chosen time, so that the mean observation time will be that which was required. The observed altitude is then corrected and compared with the calculated altitude and an intercept obtained at once.

32. Special tables have been issued as a loose enclosure to the Astronomical Navigation Tables, by means of which a correction may be found in cases where there is a time difference between the calculated and observed altitudes, such as might occur when it is not possible to make the observation at the exact predetermined moment.

FURTHER STUDY.

PRECESSION.

1. When a gyroscope is set spinning on a taut string, the axis does not remain pointing in one direction, but gradually moves round in a circle, maintaining the same angle of slope, but changing the direction in which it points.

The earth, spinning like a huge gyroscope, keeps its axis at a constant angle ($23\frac{1}{2}°$ to the plane of the orbit), but the direction in which the axis points changes slowly against the background of the celestial sphere.

The time required for a complete circle to be traced out on the celestial sphere by the pole of the earth's moving axis is 25,800 years, being a yearly movement of only 50″ of arc.

2. This change in direction of the axis will cause the equinoctial to move, since it is the projection of the earth's equator. The stars, being fixed, will gradually change their S.H.A. and Declination, since the plane of the equinoctial is the datum from which these measurements are made. Thus each consecutive issue of the Air Almanac shows a slight change in the tabulated values for S.H.A., Declination and Pole Star " Q " Correction.

3. Figs. 40 and 41 show the celestial sphere with a section cut away to reveal the earth at the centre, in the year 1942, and after a period equal to half the 25,800 year cycle, being the year 14,842, when the celestial pole has traced half of its complete circle among the stars.

Notice how Regulus, in the constellation of Leo, will change its Declination from about 12° North to quite a large southerly value.

Besides changing the S.H.A. and Declination of the stars, and apparently moving Polaris away from true north, this slow change in the direction of the earth's axis is also changing the position of the Seasons.

THE SEASONS.

4. The tilt of the earth's axis away or towards the sun is the cause of the seasons. As the earth moves in its orbit around the sun once a year, the
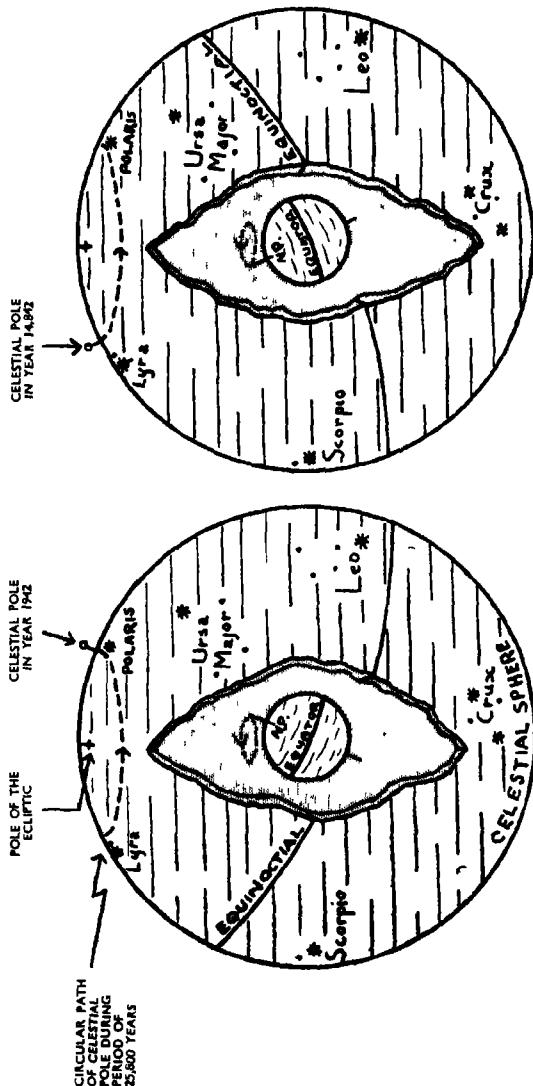
THE THEORETICAL CELESTIAL SPHERE
CUT AWAY TO REVEAL THE EARTH—
YEAR 1942. NOTE THAT THE NORTH
CELESTIAL POLE IS NEAR THE STAR
POLARIS.

Fig. 40.

THE CHANGED DIRECTION OF THE
EARTH'S AXIS AFTER COMPLETION
OF HALF THE 25,800 YEARS CYCLE :
THAT IS, IN YEAR 14,842.

Fig. 41.

axis remains pointing in one direction (see Fig. 44), and the north end of the axis points towards the sun at one time of the year, and away from it six months later.

When the direction of tilt is most nearly towards the sun (when the sun has maximum northerly Declination), the earth is said to be at the Summer Solstice. When the tilt is a maximum away from the sun, then the earth is at the Winter Solstice.

5. The earth travels around the sun in an ellipse, the sun being at one focus of this ellipse. The distance between the earth and the sun varies from about 91,500,000 miles in northern Winter to 94,500,000 in northern Summer. The points along the earth's orbit at which it is closest or farthest from the sun are called Perihelion and Aphelion respectively.

6. It must be remembered that seasonal temperature changes are not caused by the earth's distance from the sun, but by the angle at which the sun's rays fall on any particular latitude. The sun is only three per cent. closer at its closest point (northern Winter) compared with its most distant point (northern Summer). Other factors such as the tilt of the axis have far greater effects in producing temperature variations.

7. The two points on the earth's orbit where the axis is at right angles to the sun's rays are called the Equinoxes. The sun lies over the Equator with nil Declination and north and south hemispheres of the earth receive equal warmth. At the Spring Equinox the sun is on the equinoctial and is in the process of moving from south to north Declination. At the Autumn Equinox the sun is on the equinoctial moving from north to south Declination.

8. The seasons depend on the direction of slope of the earth's axis relative to the sun ; but we have seen that precession is gradually changing the direction of this slope. This gradual change must also produce a change in the positions of the seasons. The moment at which the axis is pointing a maximum towards the sun (Summer Solstice) will occur 50″ sooner each year, and in the same way the positions of the equinoxes are moving westwards by the same amount annually.

THE DAY.

9. As the earth moves around its orbit once a year, so it rotates on its own axis once per day. Measured relative to the sun, there are 365.24219

G

Mean Solar Days in a Tropical year. To avoid confusion in the construction of the calendar, the year is considered as being 365 days, and adjustments such as Leap Year are made periodically in order to keep in step with the true length of the Tropical year. The year thus kept by the calendar is known as the Civil year.

THE SOLAR DAY.

10. In deciding the number of days in the year, however, account must be taken of the length of the day, and on investigation it will be seen that relative to the sun, a day varies in length at different times of the year.
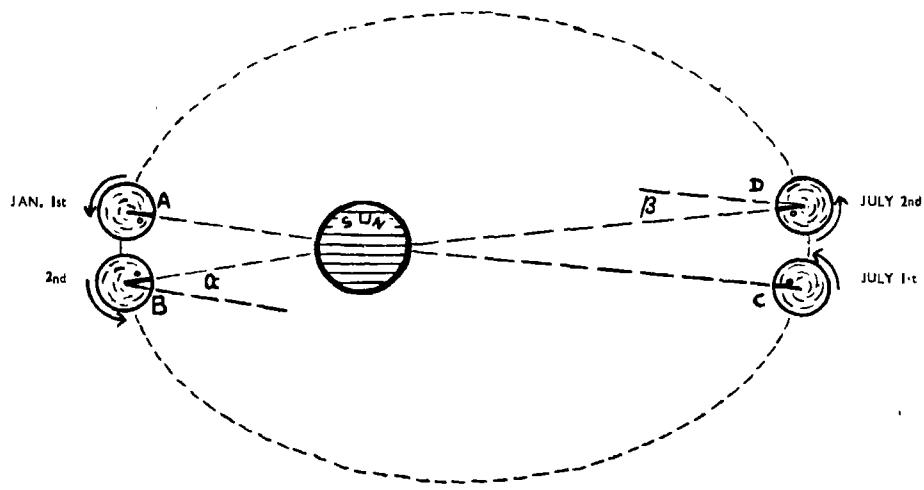
Fig. 42.

A Solar day is the time taken by the sun in crossing a given meridian on the earth twice. In Fig. 42, suppose the earth moves from A to B along its orbit between January 1st and 2nd ; in order that the sun may cross the meridian 0 a second time, the earth must rotate through the extra angle α.

Between July 1st and 2nd, however, the earth moves from C to D and the sun will cross meridian 0 a second time after the earth has rotated through the extra angle β. Since the distance of the earth from the sun is greater in Summer than in Winter, the angle β is less than angle α, thus throughout the

year the solar day varies its length, depending at any instant on the earth's distance from the sun.

11.   It would be very inconvenient for the length of the day to vary at different times of the year, and so all the day-lengths are meaned together to give a Mean Solar Day of constant length, subdivided into twenty-four hours of (Greenwich) Mean Time.

Since this mean solar day is not exactly the length of two meridian transits of the sun, at 12 o'clock G.M.T. each day, the sun will not necessarily lie exactly over the Greenwich meridian.

THE SIDEREAL DAY.

12.   So far we have only considered the rotation of the earth measured against the sun. If it is measured against the background of the stars, then two transits of a given star across a meridian will take place after exactly 360° of rotation of the earth, since the stars are so far distant that the earth's movement along its orbit will have no effect on the apparent direction of the star. Measured in terms of G.M.T. this exact rotation takes 23 hrs. 56 mins. 4.06 secs. A mean solar day, being 24 hours, is thus nearly 3 mins. 56 secs. longer than a sidereal day.   This extra amount of nearly 4 minutes is the mean of the time taken by the earth in rotating through the extra amounts α and β in Fig. 42.

From this difference in the lengths of the sidereal and solar day a more satisfactory explanation can be given for the progressive change in position of the stars at a given moment each night.

If we kept time by the sidereal day, then the stars would be in identical positions in the sky at, say, 12 o'clock each night throughout the year.   But since time is kept by the sun, and the mean solar day is longer than the sidereal day, the stars will appear to move forward a little from east to west at 12 o'clock each night ; they are rising and setting 3 mins. 56 secs. earlier each successive night, until after a year the whole celestial sphere will have apparently made a complete revolution.

THE MONTH.

13.   The sub-division of Time into years and days is based on the movements of the earth around the sun.   The lengths of the months, however, are quite arbitrary, and a brief description of their evolution will be enough to illustrate the haphazard manner in which the civil year has been divided up.

Before the coming of Cæsar, March was the first month in the year, and September, October, November and December, as their names imply, were the 7th, 8th, 9th and 10th months. Cæsar, however, made January the first month, but did not change the numbers by which the other months were known. July, the fifth month from March, had a name indicating " Fifth," but Cæsar changed it to its present name. He also decided that all the odd numbered months from January should have 31 days, and the even months 30 days, excepting February, which would have 29 days and 30 every fourth year.

When, however, Cæsar's nephew Augustus became Emperor, the Roman Senate renamed the month " Sextilis " to be August, and spoilt the whole calendar to flatter the Emperor's vanity by taking a day from February and adding it to August, thus making the Emperor Augustus's month as long as his Uncle's. Then to avoid three consecutive months of 31 days, several other changes were made between the long and the short months, to give the arrangement we have now !

It has been advocated in many quarters that the system should be changed to 13 months of exactly four weeks each, and one extra day that is in no month, which could be associated with some festive occasion such as Christmas Day. Such a system would have many advantages, not the least of which would be that certain days of the month would always fall on a Monday, and so on. To persuade the nations to make such a sweeping change, however, would be another matter.

THE ECLIPTIC.

14.   It is not easy to obtain a clear conception of small changes in the positions of heavenly bodies, because their daily path across the sky due to the earth's own rotation tends to predominate over any less obvious movement.

Forgetting for a moment the daily rising and setting of the Sun, Fig. 43 shows how it traces a path around the celestial sphere in the course of a year. An observer on the earth, moving around the sun, sees it progressively in a new part of the celestial sphere, in the direction of the arrows. All these directions join up to make a Great Circle on the celestial sphere—the apparent path of the sun in the course of a year—called the Ecliptic.

The sun moves from Declination 23½ North in summer to 23½ South

in Winter, and at each equinox the Declination is zero. This can be seen in Fig. 44, where the Ecliptic is shown with respect to the Equinoctial.
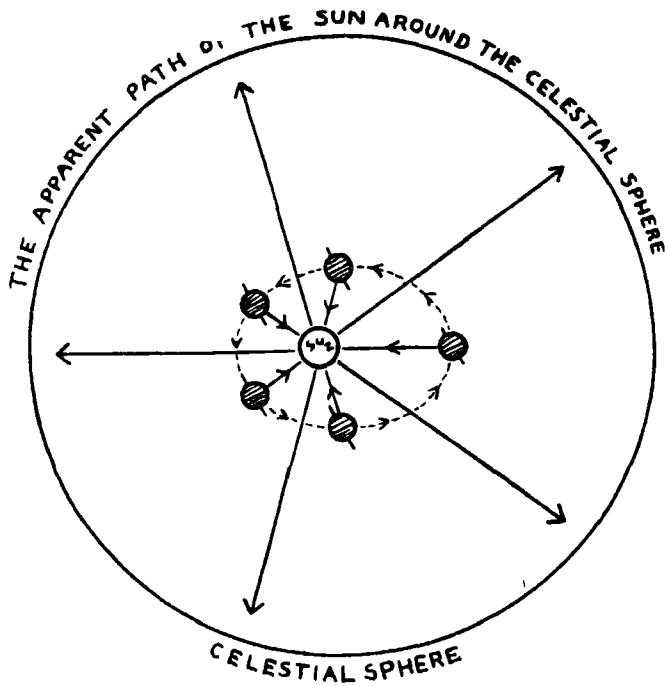
Fig. 43.

15. The Ecliptic is sometimes used by astronomers as a datum line for a co-ordinate system called celestial latitude and longitude, similar to, but not coincident with the Declination and Hour Angle method.

Celestial latitude is measured from 0°—90° from the Ecliptic north or south to the Poles of the Ecliptic and celestial longitude is measured eastwards along the Ecliptic from the First Point of Aries. (Spring Equinox.)

THE FIRST POINT OF ARIES.

16. The point where the Ecliptic cuts the Equinoctial when the sun is travelling from south to north Declination is known as the First Point of Aries, and it is the datum point on the celestial sphere for measurements of S.H.A., Right Ascension or celestial longitude.

Due to precession, the plane of the Equinoctial is gradually changing with respect to the ecliptic, completing one whole " oscillation " in the course of 25,800 years ; from Fig. 44 it will be seen that precession is gradually moving
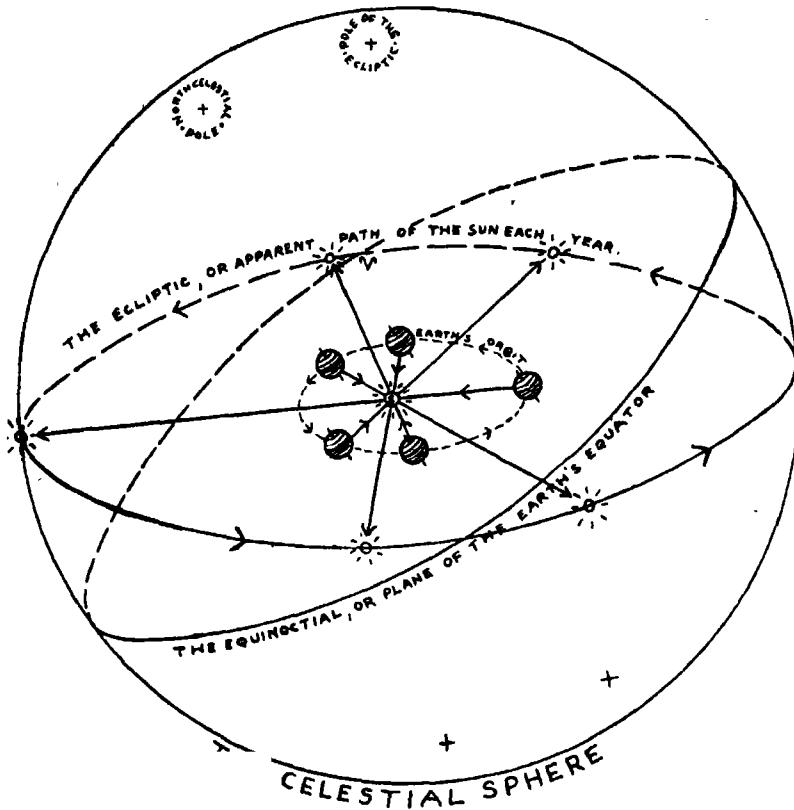
Fig. 44.

the First Point of Aries around the ecliptic at the rate of 50″ annually. When the datum point was first chosen and named, it lay in the direction of the constellation of Aries on the celestial sphere, but since then it has moved through some 30 degrees to its present position in the constellation Pisces. (The Fishes.)

RIGHT ASCENSION.

17.   The term S.H.A. has come into being fairly recently and is not in universal use.   Astronomers and sea navigators use the expression " Right Ascension " when measuring angles from the First Point of Aries.

Whereas S.H.A. is always measured westwards in arc from Aries, Right Ascension is measured eastwards, and usually in terms of time rather than arc.

Thus :

SHA Star=360°—RA Star

or   SHA Star (in Degrees) =24 hrs.—RA (in Time).

For example :

SHA 300°=24 hrs.—RA.

∴   RA =24 hrs.—300° (300°=20 hrs.)

∴   RA =4 Hours.

SEMI-DIAMETER.

18.   Since a sea navigator has an horizon which always gives him a perfect datum for measuring altitudes, a marine sextant does not contain a bubble, the horizon line being used in its place, with a correction known as Dip allowing for the observer's height of eye.

With such an horizon line, it is difficult to superimpose a large body such as the sun or moon accurately, the usual practice being to place the lower edge, or limb as it is called, of the sun or moon in grazing contact with the horizon, and adding half the angular diameter of the body, the result being the true altitude of the centre.

Applied to air navigation, the only time where this method may be advisable is with a First or Last Quarter moon, where the "horned" effect may cause difficulty in locating the true centre.

In such a case the illuminated upper or lower limb may be placed in the centre of the bubble when sighting, and the moon's semi-diameter added or subtracted as applicable to obtain the true altitude.

The semi-diameter of the sun and moon varies slightly because these bodies vary their distance from the earth, the values being tabulated daily in the Air Almanac. (See Appendix A, Tables 1 and 2.)

CHAPTER SIX.

P.Z.X.

1.   The solution of the Astronomical Triangle is the basis of all astro-navigation tables, and it is thus important to understand its construction. This chapter shows how the celestial sphere may be represented on paper approximately to scale in any chosen plane, and in such a way that angles and distances shall conform as nearly as possible to their true values.

2.   The astronomical triangle lies on the celestial sphere and its three points are always made up by

The Celestial Pole,
The Observer's Zenith,
and   The Heavenly Body.

These three points are called P, Z and X respectively, and the triangle has become known as the PZX triangle.   Since it lies on the inside of a sphere it is always a spherical triangle ; its sides, instead of being straight lines, are arcs of Great Circles.   (See Fig. 45.)
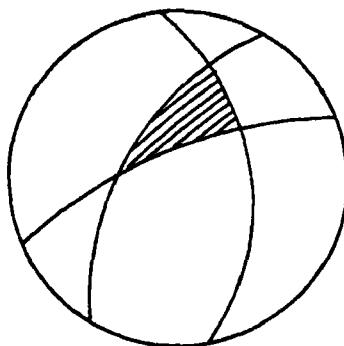
Fig. 45.

Great Circles cut a sphere exactly in two ;   their plane passes through the centre of the sphere, and their radius is equal to that of the sphere itself.

Semi-great circles are half of great circles—meridians on the earth, for example.

Small circles are circles on a sphere, whose radius is less than that of the sphere—such as parallels of latitude on the earth (other than the equator, which is a great circle).

· 3.   In building up a drawing of the celestial sphere, certain rules must be observed so that the various features to be represented shall be true to fact. As an example, the equinoctial must always be 90° from the Pole.

A good way of obtaining a clear mental picture of the situation is to divide up all the main features into two groups—items associated with the equinoctial and items associated with the horizon.
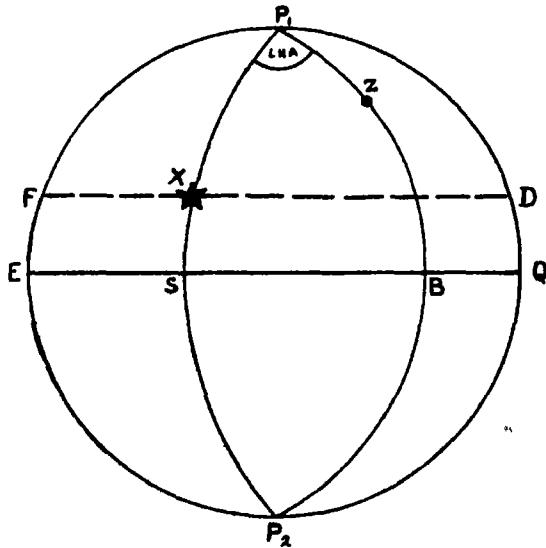
Fig. 46.

4. *ITEMS ASSOCIATED WITH THE EQUINOCTIAL.* (Fig. 46.)

(a) The Equinoctial is a great circle 90° from the Celestial Pole.

(b) Celestial Meridians are semi-great circles passing from pole to pole, and thus cutting the equinoctial at right angles. $P_1 X P_2$ is the meridian of the heavenly body ; $P_1 Z P_2$ is the observer's meridian, passing through his zenith.

(c) Hour Angles are angles between celestial meridians, measured at the pole. $P_1 Z P_2$ being the observer's meridian, angle $Z P_1 X$ is the L.H.A. of the body ; if $P_1 Q P_2$ were the Greenwich meridian, then angle $Q P_1 X$ would be the G.H.A. of the body.

(d) The circle of Declination FD is a small circle whose plane is parallel to that of the equinoctial, and which passes through the body. The circle will pass through all points having the same declination as the body.

It follows that

(e) The arc of the body's meridian lying between the body and the equinoctial is the declination of the body, SX.

(f) The arc of the meridian between the body and the nearer pole is the complement of the declination, and is known as the Co-Dec., or Polar Distance, XP_1.

(g) The arc of the meridian between the observer's zenith and the equinoctial is equal to the observer's latitude, BZ.

(h) The arc of the meridian between the observer's zenith and the pole is the complement of the latitude and is known as the Co-Lat., P_1Z.

5. *ITEMS ASSOCIATED WITH THE HORIZON.* (Fig. 47.)

(a) The Celestial Horizon is a great circle 90° from the observer's zenith.

(b) Vertical Circles are great circles passing through the zenith and the Nadir (opposite extremity to zenith), cutting the celestial horizon at right angles.

(c) The Azimuth of a heavenly body is the angular distance measured at the zenith between the observer's meridian and the body's vertical circle, P_1ZX.

(d) The Circle of Altitude AL is a small circle whose plane is parallel to that of the celestial horizon, and which passes through the body and all points having the same altitude above the horizon.

It follows that

(e) The smaller arc of the vertical circle between the body and the horizon is the altitude of the body.

(f) The arc of the vertical circle between the body and the zenith is known as the Co-Alt. or Zenith Distance, XZ.
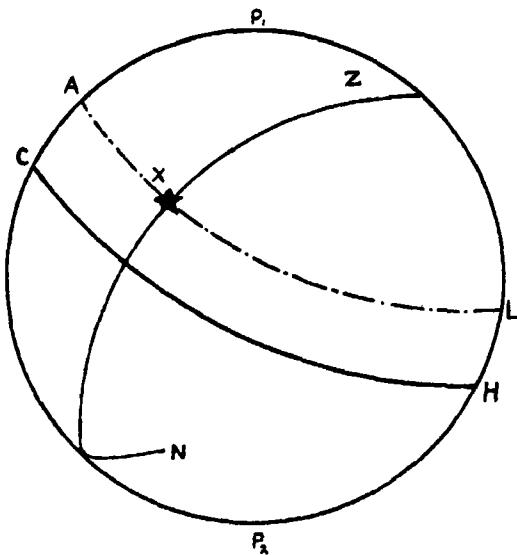
Fig. 47.

6. Having considered these two sets of definitions separately, we now bring them together into one complete diagram ; their relationship will very with the observer's latitude. Thus, if the observer were at the North Pole, the zenith and celestial pole, horizon and equinoctial, azimuth and LHA would all be coincident. As the observer changes latitude so all the items in para. 5 shift with him, while those in para. 4 remain in their positions fixed relative to the pole. Fig. 48 shows the completed drawing for an observer at 60° North. The data are the same as used in Figs. 46 and 47.

The P.Z.X. Triangle.

7. Fig. 48 shows clearly the components of the astronomical triangle.

The section of the meridian of the heavenly body XP_1 that forms one side of the triangle is equal to 90°—the body's declination (Co-Dec., or Polar Distance).
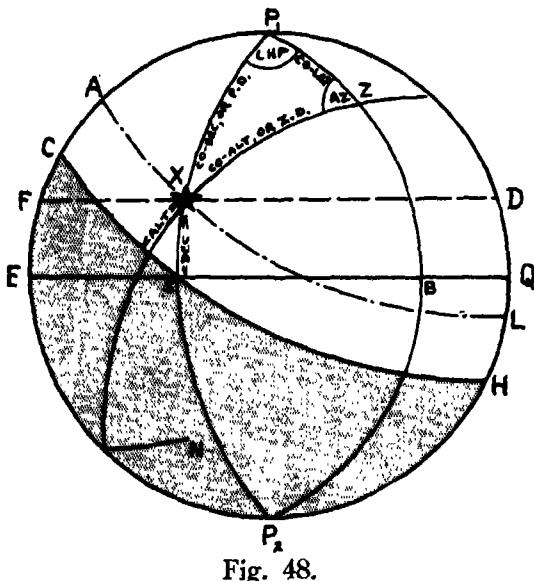
Fig. 48.

The section of the observer's meridian P_1Z that forms a second side of the triangle is equal to 90°—the observer's latitude (Co-Lat.).

The third side ZX, being part of the body's vertical circle, is equal to 90°—the body's altitude (Co-Alt. or Zenith Distance).

Of the angles, the Azimuth at Z and Hour angle at P are the only ones that enter into astronomical problems, the third angle not bearing any particular name.

Solving the Triangle.

8. In the Marcq St. Hilaire method of plotting position lines, an assumed position is taken (latitude and longitude known), and the altitude and azimuth of the body calculated from this position at the same moment as the actual sight.

The situation is then as follows, shown also in Fig. 49 :

Known	In Terms of PZX		Unknown	In Terms of PZX	
Dec.	=	$90 - XP_1$	Alt.	=	$90 - XZ$
Lat.	=	$90 - P_1Z$	AZ	=	$\hat{Z}$
LHA	=	$\hat{P}$			
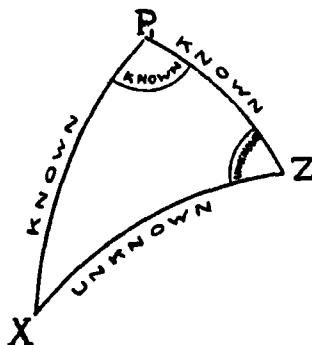
Fig. 49.

It must be remembered that the altitude measured with the sextant is not connected with the triangle to be solved. The point Z on the triangle corresponds to the assumed position, whereas the sextant altitude is taken from an unknown position. The triangle is solved in order to find the altitude from the assumed position, after which the comparison is made with the actual observation made by sextant.

As in plane trigonometry, a spherical triangle may be solved by knowing certain of the sides and angles. Thus to obtain the calculated altitude and the azimuth the triangle is solved knowing two sides and the included angle.

The Astronomical Navigation Tables.

9. Since observations with an aircraft sextant are not at the present time comparable with the marine pattern sextant for accuracy, it would be pointless to solve the triangle to within very fine limits. Under such conditions

the number of possible cases of the triangle is greatly reduced, and tables may be computed which solve the triangle by " rule of thumb " without resort to trigonometry.

The three arguments, Dec., Lat. and LHA in the Astronomical Navigation tables are given only to whole degrees. A simple interpolation table is provided in the case of the declination. For latitude, provided an assumed position is taken having a whole degree of latitude, interpolation is unnecessary. For the LHA, a longitude is assumed such that when added or subtracted from the GHA, the result is always an exact number of degrees.

Tables such as the A.N.T.'s are often called ALT-AZ Tables, their function being only to solve the Astro-triangle for ALT and AZ, given the arguments LAT., DEC. and LHA. A number of such tables have been published ; the A.N. Tables are specially for air navigation and for use in conjunction with the Air Almanac.

Plane Drawings of the Celestial Sphere.

10. An astro-navigator should be able to prove his ability and understanding of the celestial sphere by drawing it in any given plane, and for any set of conditions regarding the location of the observer and the heavenly body relative to either pole.

If such a drawing is made accurately, it should be possible to read off approximate values such as hour angle or altitude to within a few degrees of their correct calculated value. It is excellent practice to take any star sight at random from a log book of practical sights, and draw a celestial diagram in any chosen plane, testing the accuracy of the drawing by reading off the altitude and azimuth and comparing them with the true result calculated by tables.

It should be appreciated that all such drawings must be only approximate in their accuracy, since it is too laborious to project the values geometrically on to the drawing.

11. Certain rules, however, may be used as a foundation for the drawings that will keep the perspective and proportions correct, and also simplify the actual process of construction :

    (a) The centre of the drawing will invariably be 90° from the circle representing the " edge " of the sphere.

(b) *ALL* GREAT CIRCLES MUST CUT THE OUTER CIRCLE AT OPPOSITE POINTS.

(c) Small circles, whose geometric centres lie on the outer circle, will appear as straight lines. (See Circle of Declination FD, Fig. 48.)

(d) All bodies on the opposite side of the celestial horizon to the observer's zenith will be below the horizon and therefore invisible. (Shading may be used to indicate this, as in Fig. 48.)

(e) Since only half of the celestial sphere can be shown in one diagram, the Greenwich or Observer's Meridian must be carefully located with a view to keeping the star within the bounds of the " hemisphere " shown. Thus for a star with G.H.A. 060° the Greenwich Meridian must be located on the right, so that 60°, measured westwards from Greenwich, will still be on the diagram, and not " round the back " where it cannot be seen.

(f) Great circles through the centre of the diagram will always appear as straight lines.

The plane of a drawing is similar to the great circle which forms its outer circle, and is the plane through which the sphere has been sliced and the flat surface placed face down on the page. If a sphere is sliced through the Equinoctial and one-half placed flat on the page, it would be projected in the plane of the Equinoctial. Fig. 48 is in the plane of a Meridian (and anti-meridian).

12. It is required to draw the Celestial Sphere (i) in the plane of the Observer's Meridian, and (ii) in the plane of the Celestial Horizon, given the data for BETELGEUSE shown below.

(i) The data are as follows :

Latitude (of assumed position)	..		..		51°N
L.H.A.	..	..	..	..	., 065°
Declination	.,	..	..	..	..	9°N

In Fig. 50 the problem has been drawn in four stages to show how the final result is obtained.

Fig. 50a. Since the plane required is that of the Observer's Meridian, the outer circle is drawn, representing a meridian and anti-meridian meeting at the Celestial Pole, P. 90° from the pole is the equinoctial EQ, which is shown as a straight line since it passes through the centre of the figure (§11 (f)).

Fig. 50b. The Observer's Meridian must be drawn either along PE or PQ, depending on the required L.H.A. Since hour angles are always

(a)   (b)

(c)   (d)
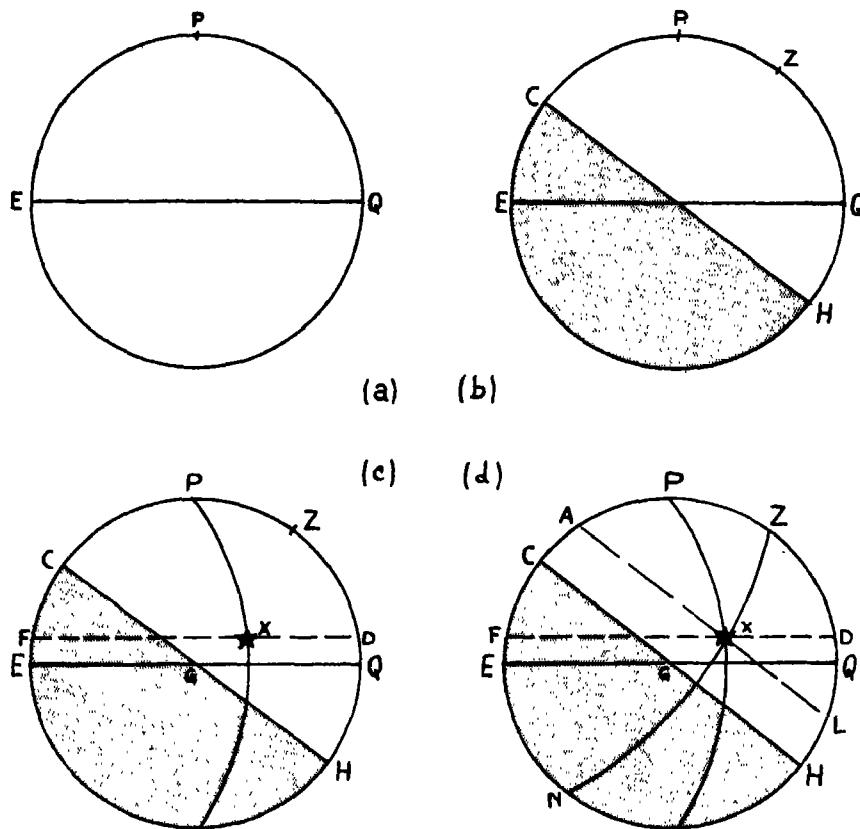
Fig. 50.

measured westwards, an L.H.A. of 065° would require the observer's meridian on the right-hand side of the diagram, in order that the star shall be in the front half of the figure. Hence PQ is chosen to be the observer's meridian, and the zenith may be drawn 51° along the arc PQ from Q. 90° from the observer's zenith is the celestial horizon ; since Z is on the edge of the diagram,

then the celestial horizon must pass through the centre, being a straight line perpendicular to a line joining Z to the centre. The whole area below the celestial horizon may be shaded, to indicate that it is not visible.

In Fig. 50c, the star BETELGEUSE has been added, from the information L.H.A. 065°, Declination 9°N. A circle of declination FD is first drawn, being a small circle parallel to the equinoctial, and 9° of arc north of it. This is estimated by the fact that the arc between E and P is equal to 90°.

The point where the circle of declination cuts the star's meridian is its only possible position ; a meridian is drawn from P, estimating the angle ZPX to be 065°, and where this cuts the circle FD is the position of BETELGEUSE.

The last stage is to complete the third side of the astronomical triangle by drawing the vertical circle through the star from Z (ZN, Fig. 50d). This is drawn by making the point N on the outer circle exactly opposite to Z. Only one curve can now be drawn through the three points ZXN ; its centre will lie on a perpendicular to ZN passing through the centre of the figure (in this case on the celestial horizon).

A circle of altitude AL may be drawn as a small circle through X parallel to the celestial horizon.

The altitude of the star BETELGEUSE may now be estimated by the length of the arc CA, using the 90°CZ as a guide (correct answer 22°).

The azimuth is estimated from the angle PZX. This angle is seen to be a little over 90° (correct answer 105°) ; since azimuths are usually measured at the zenith eastwards from true north the true azimuth will be the obtuse angle PZX, that is $360° - 105° = 255°$.

★

(ii) To draw the diagram given the same data in the plane of the Celestial Horizon.

Fig. 51a. Since the plane is that of the horizon, the centre of the figure will be the zenith, and the outside circle the celestial horizon.

Fig. 51b. The celestial pole may be drawn at any convenient position 90°—LAT. from Z. It could equally well have been put below or to the left or right of Z provided it was a distance from it equal to the compliment of the latitude.

H

The observer's meridian is now drawn from P through Z. Since meridians are great circles, and Z being at the centre, PZ must appear as a straight line.
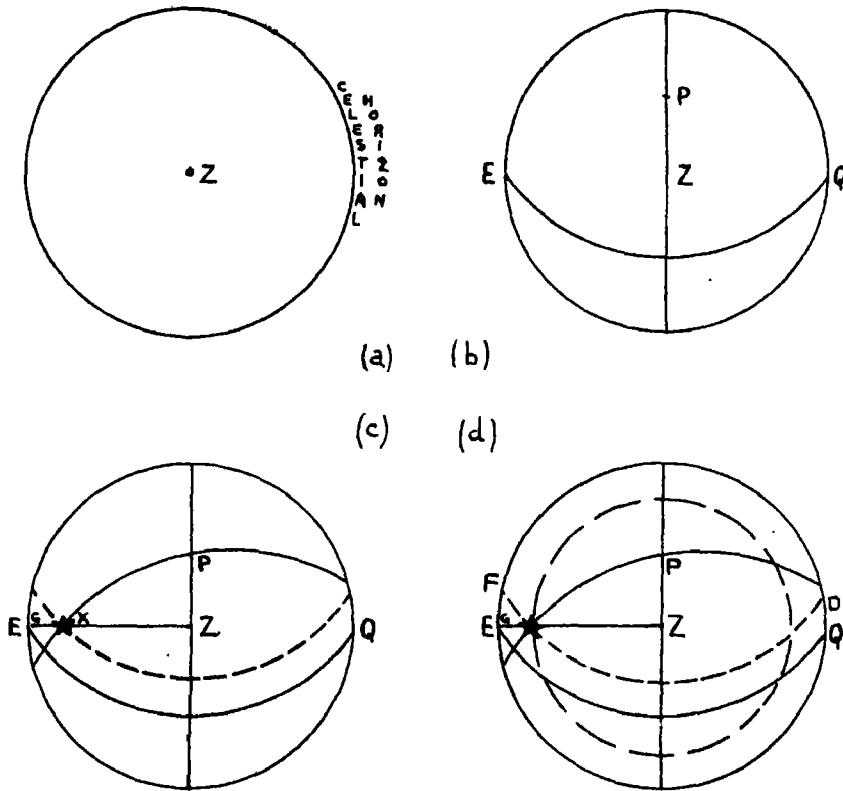
Fig. 51.

The equinoctial will cut the meridian 90° from P ; it must also cut the outer circle at opposite points (since it is a great circle). Only one curve can be drawn to pass through these points, and its centre will lie along the line PZ.

Fig. 51c. The star may now be located as in the previous example. A circle of declination FD is drawn as a small circle parallel to EQ, and an

angle at P of 065° is estimated to the West of PZ. Where this star's meridian cuts the circle of declination will be the position of BETELGEUSE. The star's vertical circle is drawn from Z to the horizon, being a straight line.

Fig. 51d completes the diagram by drawing the circle of altitude as a small circle with centre Z, parallel to the horizon, and passing through the star.

★

Geometric Proof that the Altitude of Polaris (± "Q" Correction) equals the Observer's Latitude.
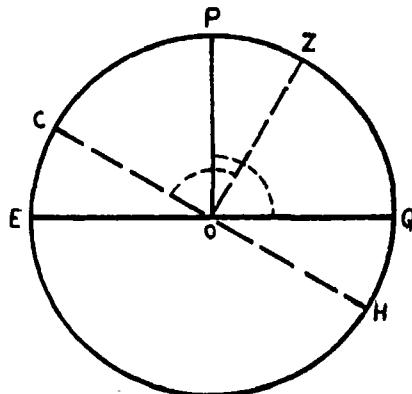
Fig. 52.

13.   On the Celestial Sphere E C P Z Q H

Let   EQ = The Equinoctial.
            CH = The Celestial Horizon.
            P = The Celestial Pole.
and   Z = The Observer's Zenith.

Required to prove that Angle COP (Alt. of Polaris) equals Angle ZOQ (Observer's latitude).

Proof.   Angle COZ = 90° (Z = Zenith, and C is on Horizon).
            Angle POQ = 90° (P = Pole, and Q is on Equinoctial).
            Since Angle POZ is common to both Right Angles,
            then Angle COP = Angle ZOQ.

                                                            Q.E.D.

CHAPTER SEVEN.

ASTRONOMY.

1.   It is natural that the navigator should become interested in astronomy and wish to acquire a general knowledge of the heavens that will assist him in understanding the appearance and behaviour of the celestial bodies.

2.   Few navigators will be prepared to accept the theoretical situation of a celestial sphere with the stars, planets and all heavenly bodies lying on its inner surface.   It is convenient as a means of demonstration and for angular measurements, but beyond this it completely fails to appreciate any differences in size and distance of the various bodies, or their correct relationship with one another.

THE UNIVERSE

NEBULAE.   THE GALACTIC SYSTEM
                            "THE MILKY WAY."

          THE SUN   GLOBULAR   OTHER
                         CLUSTERS   STARS

    THE EARTH   COMETS   OTHER PLANETS

THE MOON   THEIR SATELLITES

THE " FAMILY TREE " OF THE UNIVERSE.
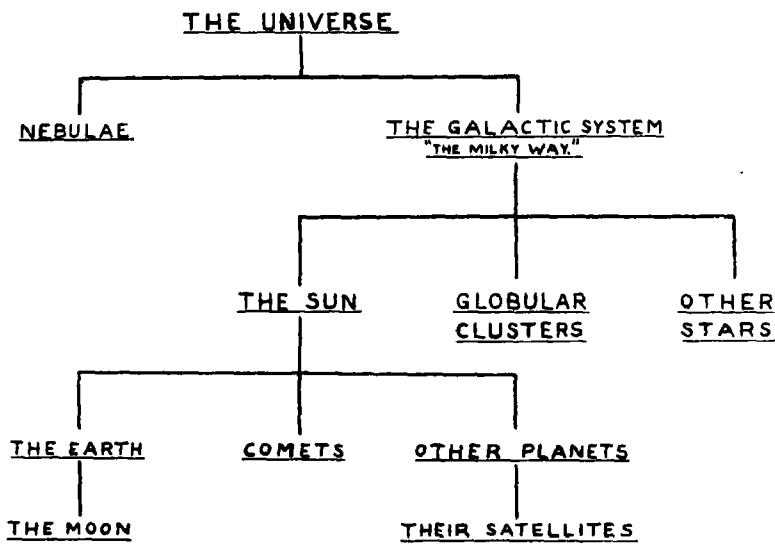
Fig. 53.

For example, although Venus on a certain night would be said to lie on the celestial sphere in the constellation of Leo, in actual fact, Venus may

only be some 50 million miles distant, while the stars in the constellation may be 50,000,000 million miles away !

3. It is almost beyond human imagination to visualise the distances involved in astronomical measurements. It takes so long for light from the distant star clusters to reach the earth that the image of these stars is formed by light which actually left the stars before man was civilised. Even the light from the closest stars travels through space for $4\frac{1}{2}$ years before it reaches the earth.

It is a mistake to imagine that even the most powerful telescopes will produce any increase in the size of a distant star. No matter how large the telescope within present standards, a star will still appear as a point of light. The planets, on the other hand, present a very different appearance, being capable of considerable enlargement and revealing much detail, such as the rings of dust particles around Saturn and the satellites revolving around many of the planets, similar to our own Moon.

4. Fig. 53 gives some idea of the composition of our Universe, and will serve well to demonstrate the insignificance of the earth with respect to the heavenly bodies. This is a very different picture to that believed long ago when the earth was thought to be the central object of prime importance around which all the stars rotated.

THE MOON.

5. Undoubtedly part of the earth long, long ago, the moon now revolves around it at an average distance of about 239,000 miles, the plane of its orbit being inclined to that of the earth at an angle of 5° 8′. It completes one circuit of the earth in $27\frac{1}{3}$ days, and also rotates on its own axis in exactly the same period, thus permanently presenting the same face to the earth. The " back " of the moon is always turned away from us, although a little more than half has been seen due to its varying speed in orbit, and to a slight inclination of its axis from the plane of its orbit. These movements which allow us to see a little " around the back " of the moon are called librations.

The length of a day on the moon is fourteen times the length of our day, and having no atmosphere the surface attains very great extremes of temperature between the long days and nights, in the nature of 200°F. during the lunar day and 200°F. below zero during the night. It is fortunate that the blanketing effect of the earth's atmosphere prevents our temperatures from reaching such alarming extremes.

When the moon lies between the earth and the sun, it is " new " (" in conjunction ") ; when it lies on the opposite side of the earth to the sun it is " full " (" in opposition ").

Should, however, it pass exactly between the earth and the sun, it will cut off the sunlight falling on the earth over a small area and cause certain places on the earth to see an eclipse of the sun. On the other hand, should it lie exactly opposite to the sun on the other side of the earth, such that sun, earth and moon are in a straight line, the earth will stop the sunlight from reaching the (otherwise) full moon, and the earth's shadow will be seen to cross the moon, causing an eclipse of the moon.

An eclipse of the moon is the more common of the two because it may be seen from many parts of the earth. A solar eclipse is comparatively rare at any given place, since the area on the earth covered by the eclipse is quite small. The more commonplace lunar eclipse is not spectacular, however, since all that is seen is a gradual shading over of the moon ; a solar eclipse, blotting out the sunlight, is capable of producing apparent night conditions during the day.

THE PLANETS.

6. The earth is one of the nine planets ; it takes third position from the sun in distance, Mercury and Venus being " Inferior " planets—their orbits are smaller ellipses around the sun within that of the earth (see Fig. 54). Outside the earth's orbit, rotating around the sun on increasingly larger orbits, are Mars, Jupiter, Saturn, Uranus, Neptune and Pluto.

Each planet has its own particular orbit around the sun, and each travels around its orbit at a different speed. Thus their relative positions are constantly changing within certain limits. Those that happen to be on the opposite side of the sun to the earth will not be visible at night because the observer is turned away from the sun. Those with a smaller orbit around the sun than the earth will only be visible by looking in the same approximate region of the sky as the sun ; that is just after sunset or a few hours before sunrise.

Since the planets travel around the sun in a narrow belt of some 9° on either side of the ecliptic, they will trace a path across the sky not unlike that of the sun. Since they are viewed at night, however, they will cross the meridian at a fairly high altitude in winter and a low altitude in the summer.

The belt of 9° on either side of the ecliptic within which all the planets lie is known as the Zodiacal belt, and the twelve parts into which it is divided are
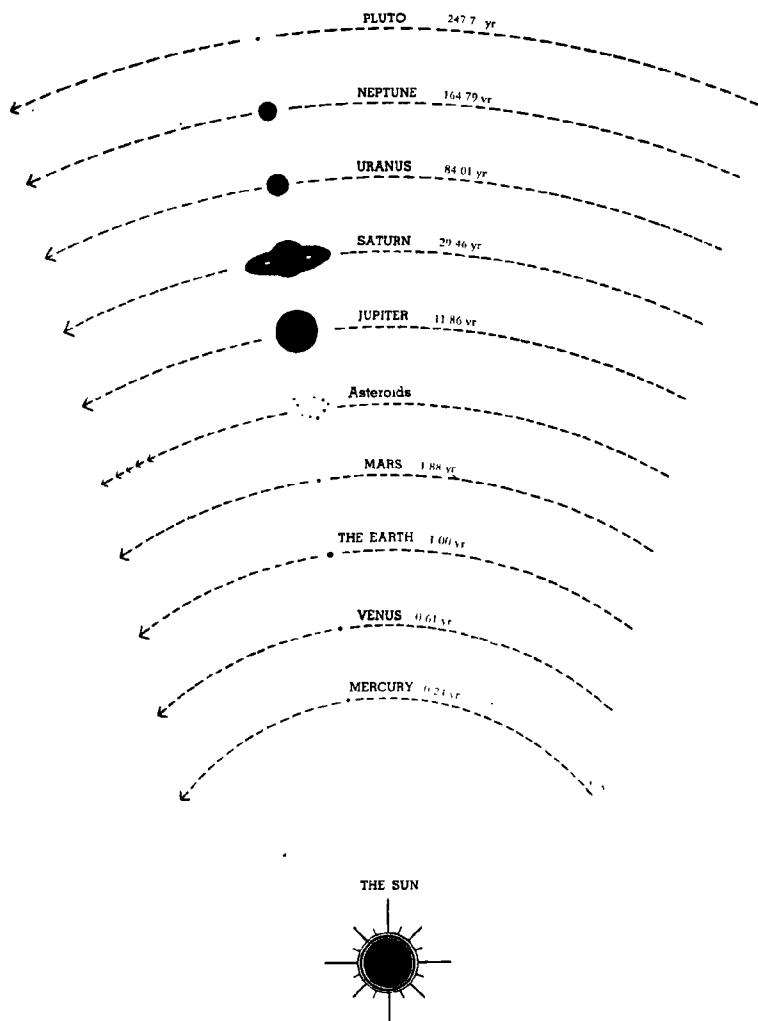
Fig. 54.   THE PLANETS.

SHOWING THEIR RELATIVE SIZES AND POSITIONS WITH RESPECT TO THE SUN.

NOTE.—DRAWN TO SCALE, THE SUN'S DIAMETER WOULD BE $2\frac{1}{2}$ INCHES.   DISTANCES OF THE
PLANETS FROM THE SUN ARE NOT SHOWN CORRECTLY

called the signs of the Zodiac, the names being taken from the constellation lying within or near to each section.

THE SUN.

7.   The sun is similar to the many thousands of stars visible on a clear night.   It is neither larger nor hotter than most other stars, but is just an average specimen that might be picked at random from the universe.   Due to the earth's insignificant status revolving around the sun, however, its proportions are to us naturally far greater than the other stars, just as a dog, walking through a park at the heels of his master, sees him as the only being of importance by comparison with the other humans scattered through the park.

The sun is about 109 times as large in diameter as the earth, or 864,000 miles.   It rotates on its axis once every 25 days, the axis being tilted with respect to the plane of the earth's orbit at an angle of $7\frac{1}{4}°$.

The only noticeable changes which the sun undergoes from day to day are the appearance of sunspot groups.   They consist of depressions in the hot surface of the sun of some 500 miles depth, being at a lower temperature than that of the sun's disc.

Sunspots can often be seen with the naked eye through a tinted screen, while a small telescope is capable of showing them in fair detail.

Although relatively short-lived, the frequency of appearance of spot groups fluctuates in a cyclic manner over an average period of eleven years. Streams of electrified particles pour outwards from the spots at a speed of about 1,000 miles a second, and may encounter the earth about twenty-four hours after they cross the central meridian of the sun.   Should this happen, the influence of the earth's magnetic field causes the stream to move spirally inwards in the neighbourhood of the two magnetic poles, and as they reach the earth these particles give rise to currents of one or two million ampères in the upper air.   This causes magnetic storms, the Aurora Borealis, interference with wireless transmission and possibly deviation of the magnetic compass.

Navigators should check their position by astro when the Aurora is active in the northern sky, and warning them that the magnetic compass may be affected.

THE STARS.

8.   The nearest visible star, excluding the Sun, is Alpha Centauri, being some 270,000 times further away from the earth than the sun, or 4¼ light years, (A Light Year is the distance that light, moving at 186,000 miles per second, can travel in a year.)

.   SIRIUS, also a relatively close star, is 8.65 light years away, and PROCYON 10.4.

Apparent brightness, however, is not a measure of the distance of the stars.   One might think that the bright stars in Orion were as close as SIRIUS or PROCYON, since their brilliance compares favourably.   In fact, they are too far away to be measured accurately, probably at least 50 times more distant than SIRIUS.   RIGEL is so far away that it appears to us as an average first magnitude star less bright than SIRIUS, whereas it is actually 10,000 times brighter than the sun, compared with SIRIUS being 26 times as bright. If the barrier of distance could be removed, RIGEL would be one of the brightest stars in the heavens.

The temperature of a star may be determined by its colour.   Just as a poker varies its colour from dull red to a whitish red with increase in temperature, so the spectrum of a star will reveal its approximate temperature, ranging from dull red for a cool star through yellow, white and blue to violet for an exceedingly hot one.   The temperatures of the stars cover an enormous range, the sun being a fairly cool yellow star at 6,000°C. BETELGEUSE and ALDEBARAN are red and orange stars, having temperatures of 2,600°C and 3,000°C respectively.   At the other end of the scale are RIGEL and SIRIUS, both white stars at 11,000°C and 16,000°C respectively, while MIRZAM, a second magnitude star near SIRIUS, is bluish white with a temperature of 25,000°C !

THE GALACTIC SYSTEM.

9.   All the stars we have considered so far—that is those visible to the naked eye—are part of a system that is quite small in comparison with the universe.

The stars are not scattered vaguely through space like so many snowflakes.   They form part of a group known as the Galactic System or Milky Way.   The system is described by Sir James Jeans as being in the shape of a huge currant bun.   All the stars lie in the layer of butter through the centre of the bun, the sun being about a third of the way out from the centre.   The stream of stars seen on a clear night and known as the milky way is this flat

layer seen from the inside. They are infinitely further away than the bright stars such as RIGEL or CAPELLA, all the latter lying in an area of the bun in the immediate vicinity of our solar system. The centre of the bun lies in the Scorpio-Sagittaris region of the milky way, where it is brightest and most conspicuous, although it is improbable that we can ever see as far as the other side of the bun.

GLOBULAR CLUSTERS.

10. Scattered through Sir James Jeans's bun are about 100 currants, representing groups of thousands of stars like swarms of bees, and yet outside the butter layer in which the other stars are scattered. Only a few of these clusters are visible to the naked eye, but they all lie within the shape and dimensions of the bun. The nearest of these clusters is a little over 19,000 light years away.

NEBULÆ.

11. Far, far away, this time in really large astronomical figures, lie distant star formations similar to our own Galaxy. They are so remote that the whole system can seldom be seen with the unaided eye, let alone individual stars. Through a small telescope, however, these groups are found to have a shape similar to that of our own system, except that they vary in size and flatness, depending on their stage of development and age.

These distant groups of millions of stars are far more remote than can possibly be imagined. The nearest of them is nearly 800,000 light years away. The light reaching our eyes at this moment must have left the Nebula from which it came long before the earth was inhabited !

Practical Astronomy.

12. The study of astronomy is a fascinating and instructive hobby to which many navigators have been attracted. Similarly, during the present war, a number of astronomers have assisted in the development of certain navigational instruments.

In studying distant objects, the astronomer naturally locates them by reference to the bright stars in the vicinity. In this way he is making constant reference to different sections of the sky, which results in a gradual improvement in his star recognition. The importance of a good knowledge of " stellar geography " to the navigator has resulted in the two subjects becoming very closely allied, and the wise astro-navigator memorises his stars with the aid of a small telescope and even a camera, thus combining his work with a hobby that has almost unlimited possibilities.

CHAPTER EIGHT.

THE MK. IXA SEXTANT.

1. The sextant in Fig. 56 is at present the standard instrument in service with the Royal Air Force. Its novelty lies in the mechanical process of reading the altitude sixty times at two second intervals by means of a clockwork mechanism, which automatically indicates the final average of the sixty readings.

The optical parts consist of two fully silvered plane mirrors of high quality, one being capable of rotation either in slow motion or into preset positions 10° apart, and the other having two fixed positions 5° apart which
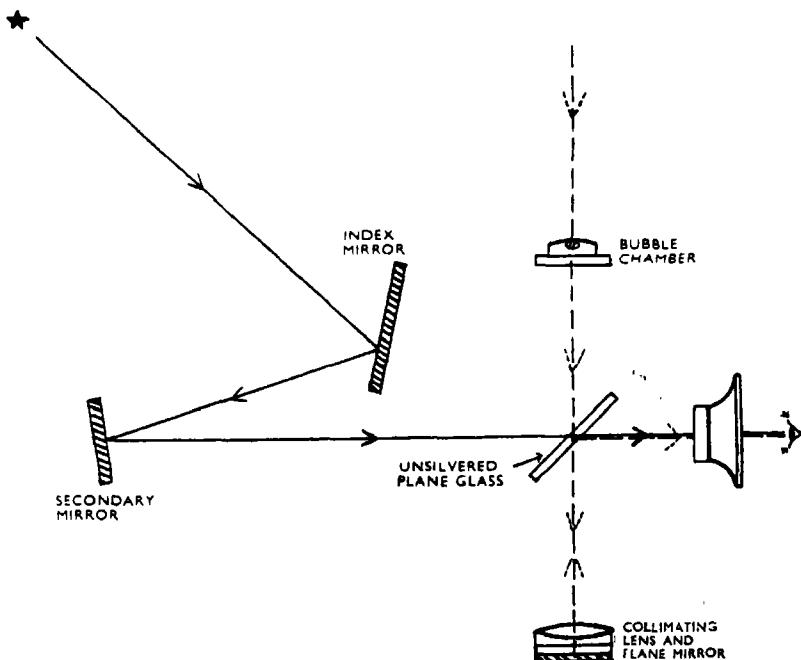
OPTICAL SYSTEM OF THE MK. IXA SEXTANT.

Fig. 55.
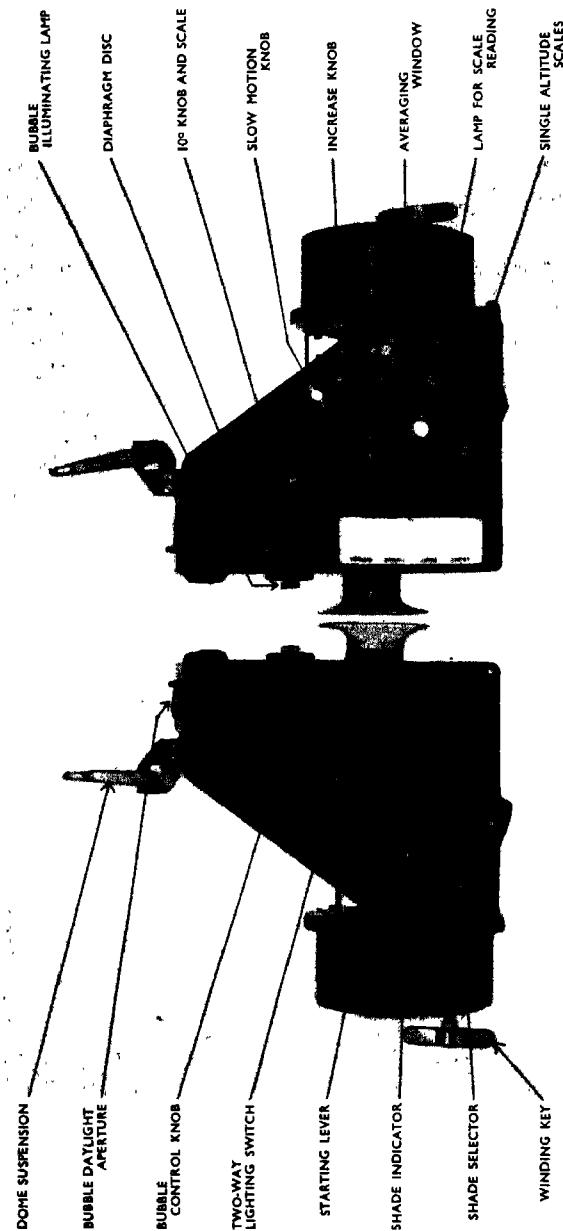
THE MARK IXA BUBBLE SEXTANT.

Fig. 56.

BUBBLE ILLUMINATING LAMP

DIAPHRAGM DISC

10° KNOB AND SCALE

SLOW MOTION KNOB

INCREASE KNOB

AVERAGING WINDOW

LAMP FOR SCALE READING

SINGLE ALTITUDE SCALES

DOME SUSPENSION

BUBBLE DAYLIGHT APERTURE

BUBBLE CONTROL KNOB

TWO-WAY LIGHTING SWITCH

STARTING LEVER

SHADE INDICATOR

SHADE SELECTOR

WINDING KEY

are controlled by the Increase knob. A glass chamber contains the bubble fluid, by which the sextant is levelled, and a collimating system consisting of a concave mirror and plane glass at 45° to the eyepiece carries the image of the bubble chamber to the eye (see Fig. 55). A disc bearing different " stops " or apertures is rotatable in front of the lamp which illuminates the bubble in the dark, thus providing a diaphragm control on the strength of the light without employing a rheostat.

2. A system of cams controls three sun shades which are employed singly or together, operated by a selector knob on the left of the instrument which has six alternative positions ranging from no shades at all to a combination of all three.

OPERATION OF THE BUBBLE CHAMBER.

3. When viewed through the eyepiece, the bubble chamber appears as a circular aperture on the edge of which is a small opening in the position
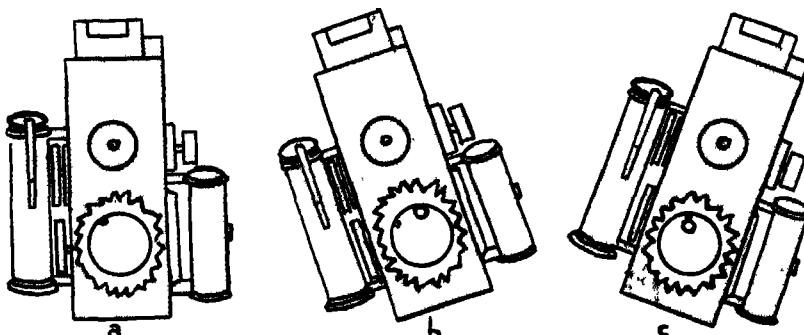
BUBBLE CHAMBER OF THE MK. IX SEXTANT.

The eyepiece has been " cut away " to reveal the bubble chamber within.

Fig. 57.

shown in Fig. 57 (*a*), connecting the chamber to the bubble control system. When the bubble control knob is tensioned by turning towards the eyepiece, air is forced from the reservoir into the chamber, providing the bubble required. The size of the bubble is controlled by the amount of tension applied by means of the control knob.

TO OBTAIN A BUBBLE.

4.   Hold the sextant to the eye and with No. 2 or 3 shade combination selected, slowly turn the Bubble Control knob clockwise until tension is felt, and a stream of bubbles enters the chamber.   Hold the sextant upright or tilted slightly to the left (so that the bubble is carried away from the opening while tension is released) and slowly slacken off the control knob until it is free.   (Fig. 57 (*b*).)

TO REMOVE A BUBBLE, OR REDUCE ITS SIZE.

5.   Hold the sextant to the eye, and turn the Bubble Control knob clockwise until half a turn of tension has been applied.   Tilt the sextant about 20° to the right (Fig. 57 (*c*)) to bring the bubble over the aperture, then slowly slacken off tension on the control knob until the bubble has been sucked back into the opening at the edge of the chamber.

ALWAYS REMOVE THE BUBBLE AND RELEASE TENSION AFTER USE.

6.   It is absolutely essential, when returning the sextant to its case after use, to ensure that the bubble has been removed from the chamber, and tension on the control knob has been released.

If, when using the sextant, the bubble shows a tendency to decrease in size or even disappear, slight tension may be left on the control knob during the whole period of sighting.

FUNCTION OF THE CLOCKWORK MECHANISM.

7.   The predecessor of the Mk. IXA sextant averaged the result of six consecutive observations of the heavenly body, this operation covering a period of about 30 seconds.   From the explanation given in Chapter 4, this period is undoubtedly too short, and the graph in Fig. 31 shows how great an error might be given if the observations happened to cover the period of a peak maximum or minimum value in altitude.

To increase the accuracy of results obtained with this instrument, it became necessary to repeat the routine of averaging six shots twice or even three times over.   By careful operation it was possible to run multiples of six shots together, but the sextant drill became complicated, and errors due to faulty manipulation often occurred.   It was only possible to obtain 18, or with great skill 24 shots in two minutes, and as these were not evenly spaced

over the period they could not be a strictly accurate measure of the mean altitude.

8. With the Mk. IXA sextant, a new standard of accuracy has been made possible, and under good conditions a position line error in excess of two miles should seldom occur.   This permits even greater accuracy to be expected from an astro fix than one obtained from radio loop bearings, where distance between the aircraft and the ground beacon may be great enough to produce errors of one or two miles for every degree of error in the loop bearing.

The two minute period during which the clockwork mechanism is recording the altitude every two seconds is ideal for most aircraft, and the frequency of observation ensures that every change of altitude is averaged into the answer, even during the brief moments of maximum errors, shown in Fig. 31.

Procedure in the Air.

9. *IMMEDIATELY BEFORE SIGHTING.*   (In Daylight.)

(*a*) Select a suitable shade, and obtain a bubble, as in para. 4.

(*b*) Wind clock fully.

(*c*) Hold the sextant horizontally, bubble central, pointing towards the heavenly body.

(*d*) Depress 10° Setting knob and slowly turn it, keeping the bubble central, until the heavenly body comes into view.   Release the 10° Setting knob into the position which locates the body as close to the bubble as possible, BUT ABOVE IT.

(*e*) If the nearest position of the 10° Setting knob puts the body some way above the bubble, then push the Increase knob up, which will move the body 5° down to the bubble.   If the body remains a little above the bubble, leave Increase knob up.   Should the body go below the bubble, return Increase knob to its down position.

(*Note.*—The Increase knob need not be used. It is only a device to reduce the distance between the bubble and the nearest position of the heavenly body's image, and thus the amount of winding necessary on the Slow-motion knob to bring them together.)

10. *IMMEDIATELY BEFORE SIGHTING.*   (At Night.)

(*a*) Wind clock fully. (Bubble lamp will not light unless clock mechanism is wound.)

(*b*) Set shade counter to zero, and turn Diaphragm Control disc to a large opening.

(*c*) Press Two-way lighting switch with the left thumb to the right.

(*d*) Obtain a bubble, and reduce light intensity by Diaphragm Control disc.

(*e*) Set zero on 10° Setting knob, and without illuminating bubble, point sextant like binoculars straight at the body, when it should be seen at once in the line of sight, since the mirrors are set at zero elevation.

(*f*) Press 10° Setting knob in, and slowly bring the sextant down to the horizontal, at the same time KEEPING THE BODY CONSTANTLY IN THE FIELD OF VIEW by turning the 10° Setting knob as necessary. When horizontal, illuminate the bubble without taking the eye off the body, and when the bubble is in the centre of the field, allow the 10° Setting knob to slip into the nearest position of the body above the bubble.

(*g*) Test whether Increase knob is needed in the up position.

11. *SIGHTING PROCEDURE FOR ALL BODIES.*

(*a*) Check that clock is fully wound.

(*b*) Wind Slow-motion knob until bubble and body coincide, then note watch reading.

(*c*) Depress Starting Lever, and maintain as accurate coincidence as possible between bubble and body continuously until clock stops.

(*d*) Note watch reading.

(*e*) Note sextant reading, adding figure on 10° Scale to the figure in the Averaging Window.

12. *SINGLE ALTITUDES.*

If a run of two minutes is not possible, or if the sextant is being used on the ground, the clock mechanism is not used, and the altitude is read as the sum of the readings on the 10° Scale and the Single Altitude Scales. The Averaging Window on the side of the clock is not used.

Sextant Technique.

13. At all times the sextant bubble should be kept fairly small. It may be found that the bubble size tends to increase or decrease while the

sextant is in use. If this happens, the bubble must be adjusted before it becomes too large or too small for accurate sighting. Slight tension may be left on the Bubble Control knob if there is a tendency for the bubble to decrease in size.

When observing the sun, ensure that a dark shade is in position before putting the sextant to the eye, as the sun image is bright enough to damage the eye if viewed without shades.

When observing the moon in daylight, use a pale coloured shade, sufficient to darken the moon and surrounding sky so that the bubble, which is less brilliantly illuminated through the Bubble Daylight aperture, may be seen.

When observing the moon at night, the largest Diaphragm opening should be used for the Bubble Illuminating Lamp. If the moon is full and very brilliant, No. 1 shade may be used to reduce the glare and improve the visibility of the bubble.

When observing stars, avoid long searches with the sextant to the eye by following these rules :—

(a) Always check that the shade indicator is at zero.

(b) Always use the sextant like binoculars as in para. 10e, ensuring that the 10° Scale is set at zero and not at " D " (10° Depression).

(c) Keep the other eye open while guiding the sextant on to the star, and as often as possible if a search has to be made.

(d) Do not illuminate the bubble and thus dazzle the eye until the sextant has been lowered to the horizontal, and the star is still clearly visible in the field of view.

Notes.

14.   1.   Always wind the clock mechanism fully, but turn the key gently.

2.   Keep the bubble size within reasonable limits ; a large bubble gives less accurate coincidence. A very small one is sticky and unresponsive.

3.   Open the sextant case when it is intended to climb to an altitude at which the temperature may be low.

4.   NEVER make observations through perspex other than the standard astro dome.

5.   On a very dim star it is sometimes easier to place it alongside the bubble rather than in the centre of it.

6.   A small prism situated in the right-hand handle of the sextant has

been designed to throw a shaft of light on to a watch worn on the inside of the observer's wrist, when the switch lever is pressed to the right.

The Sextant as a Rangefinder.

15. A fairly accurate Fix may be obtained by measuring the bearing and distance of a headland, mountain peak or lighthouse. The Mk. IXA Sextant is well suited to the measurement of angles of depression or elevation from an aircraft to some such landmark, and from this angle the range may be computed by consulting suitable tables.

The height of the aircraft is always known fairly accurately from the indicating instruments ; the height of a distant mountain range may readily be obtained from the navigator's map. By knowing the angle above or below the horizontal of the object, and the relative heights of the observer and object, the length of the base line is easily computed, and has been put into a convenient tabular form in a special table in the Astronomical Navigation Tables.

16. Angles of depression are measured with the sextant by putting the 10° Setting knob to " D " (10° depression). Using No. 1 shade and a normal bubble, the distant object is adjusted on the Slow-motion knob until it lies exactly over the bubble ; a run of sixty shots may then be made in the usual way, and the final answer in the averaging window is then SUBTRACTED from the 10° on the 10° setting scale, since turning the Slow-motion knob increases the elevation of the mirror and an increase above 10° depression will bring the answer nearer to zero. (10° depression with the increase knob up would be 5° of depression, not 15°.)

★

The Astro Dome and Suspension.

17. Not very long ago the question of facilities for the navigator was barely considered in the layout of an aircraft. Lack of space and vision would frequently make his difficult task a great deal worse. Happily the navigator's needs are now one of the important considerations that influence the design of large modern aircraft, as shown by the presence of an astro dome in almost every machine within the closest possible distance to the centre of gravity. Furthermore, such a dome will probably be fitted with seat, arm rests, a hot-air system to prevent frosting, and a suspension fitting to take the sextant (Fig. 58). The dome is easily removed so that on warm nights the navigator

may take sights through the open space, and even more important, use it as an emergency exit.

Due to the curved surfaces of the perspex, an error caused by refraction is introduced which must always be allowed for immediately after observation.

18.　The sextant suspension is very helpful in steadying the sextant, and preventing fatigue in the arms. It also provides a means of locating the position of the sextant relative to the dome and thus standardising the refraction values. Without such a guide, the values of Dome Refraction for a six-foot observer would be quite different to those for one whose head barely reaches into the dome.

THE STANDARD ASTRO DOME FITTED WITH SEXTANT SUSPENSION.

Fig. 58.

A table giving the values of Dome Refraction to be applied when using a suspension is given inside the front cover of the Air Almanac. (Appendix A, Table 3.)

CHAPTER NINE.

THE ASTROGRAPH.

1. With the increasing speed of modern aircraft, and the recent development of radio assistance, the navigator is allowed less time than in the past to make use of a greater number of complicated aids, and the calculation of astro sights may not now occupy too great a part of the total time on each leg of a flight.

Thus, except when navigating on long distance flights, the Air Almanac and A.N. Tables do not share the popularity of aids such as loop bearings or radio beams where the information can be converted very rapidly into " positional " data.

2. Before passing on to other methods, however, it must be emphasised that, where circumstances permit, the tabular method remains the most reliable, and the sights so calculated have the advantage of being put on record in a suitable log book for post-flight analysis. The Nautical Almanac and Alt-Az. tables remain to this day the standard method of calculation throughout the Navy ; the Air Almanac and A.N. Tables are a simplified form of the same tables drawn up to the limits of accuracy imposed by the bubble sextant when used in aircraft.

3. Chapter 1 has shown that beneath every heavenly body may be drawn a system of curves on the earth which are concentric about the geographical position of the body, and which represent circles from all points on which the star's altitude is the same. Since the earth is circular—within the limits required—and since all the heavenly bodies lie on the celestial sphere, one set of curves drawn for, say, every 10° of altitude, will be standard in every respect for all bodies. Thus star curves of corresponding altitudes are always identical for all stars, since the stars are fixed on the celestial sphere. The only factor which causes any movement of the curves with respect to the earth is the earth's own rotation.

4. If the earth ceased to rotate, star curves could be plotted permanently on maps, and position lines obtained immediately by simply locating the curve corresponding to the complement of the altitude measured by sextant. No observation of time would be necessary.

5.　Unfortunately for the navigator, the earth revolves and the star curves appear to pass across its surface at a constant speed to the east.　An observer stationed on the earth could imagine the shadow of these curves passing through his position in a steady procession as the star, in a direction at right angles to them, rises or falls steadily in altitude in the sky.　If it reaches his zenith he will be standing as though in the centre of a target with all the curves concentric about himself.

6.　It is not possible to move the navigational map progressively across the navigation table to represent the movement of the earth, for at the rate of 15° of longitude per hour, the observer's position would soon be off the table.　Alternatively, the star curves may be moved in the opposite direction, from east to west, and the map kept stationary.
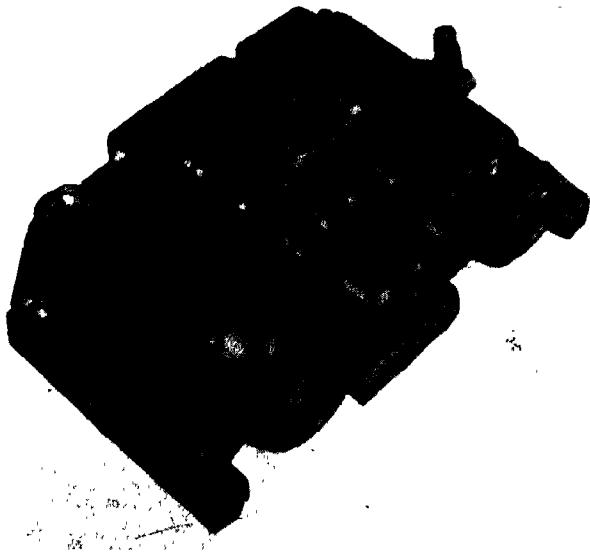
Fig. 59.

7.　The Astrograph is a simple form of projector containing a small light source and a long band of film on which selected star curves are printed.

When the lamp is illuminated, the curves are projected in black and white on to the navigational plotting sheet in such a way that :

(*a*)   The scale of the projected curves is identical to the scale of the plotting sheet.

(*b*)   The curves can be adjusted in latitude to bring their central parallel of latitude into coincidence with that on the plotting sheet.

(*c*)   The curves can be moved progressively in longitude to allow for the passage of time.

RATE OF LONGITUDINAL MOVEMENT.

8.   The speed at which the curves must travel across the map is the same as the rate of the earth's rotation relative to the stars.   The astrograph film, therefore, requires to be advanced at a sidereal rate, whereas the navigator's watch measures G.M.T., a mean solar rate, a difference of 3 minutes 56 seconds daily.   During a sidereal 24 hours the earth rotates through 360°, or 15° of longitude per sidereal hour.   During a mean solar 24 hours (24 hours of G.M.T.) the earth rotates through 360° 59′, or 15° 2.45′ of longitude per G.M.T. hour.

Thus, as the earth progresses around the sun the G.M.T. and sidereal time gradually change, the sidereal time going steadily ahead of the G.M.T. at the rate of 3 minutes 56 seconds daily, like an express train gradually pulling past a slower one moving in the same direction.

9.   And so it follows that to locate the star curves by means of a G.M.T. watch, a certain quantity of time must be added to the G.M.T. as a correction, the quantity depending on the number of days elapsed since the G.M.T. and sidereal time values coincided.   Clearly on one particular day of the year 00.00 hours G.M.T. and 00.00 sidereal time must come together.   With each following day the sidereal time goes ahead by 3 minutes 56 seconds, until after 6 months, at 00.00 hours G.M.T. the sidereal time is 12.00 hours.   Thus on that date, the quantity to be added to the G.M.T. to set the star curves correctly would be 12 hours.

10.   The astrograph film has been printed with a time scale the same size as a G.M.T. scale, although in practice it will be displaced from the actual G.M.T. by a certain number of hours each night, depending on the date.   With a daily difference of 3 minutes 56 seconds, however, the time addition for each night will be a clumsy number of hours, minutes and seconds

to be set against the Greenwich meridian on the map. Since G.M.T. is the same all over the earth, but sidereal time changes with longitude, a longitude could easily be found, close to the observer's position, on which the time addition would be a whole number of hours. For example, it is far simpler for the navigator to add 8 hours to the G.M.T. of each sextant observation and set the resulting time on meridian 2° 15′E on his map, rather than adding 7 hours 51 minutes to the G.M.T. of each observation, and setting the result on the Greenwich meridian, although each will set the star curves correctly.

11. The value resulting from this sum of the G.M.T. and the " Time Addition " is called Astrograph Mean Time, abbreviated A.M.T. It is printed along the entire length of the astrograph film close to the central parallel (see Fig. 60), and the table from which it is computed is found near the end of the air almanac (see Appendix A, Table 14). The table, consisting of two pages, one for east and one for west longitudes, covers one calendar month, and under each night of the month are selected " Setting Longitudes " to which the Time Addition, given at the top of each column, refers. It will be noted that values of G.M.T. which correspond to the A.M.T. at the top of each column are given in the right hand margin. This is because midnight does not occur at 00.00 hours G.M.T. at all longitudes. At longitude 180°, 00.00 hours G.M.T. is at midday, and if the astrograph table was compiled with this starting value, it would mean listing many unnecessary figures for the daylight hours before the table would cover the period of darkness during which the astrograph would be used. Thus opposite each setting longitude the G.M.T. of local midnight is given in the margin, and it is this value to which the A.M.T. at the top of the column corresponds.

12. To use the table, the correct column is selected for the night in question, and a setting longitude picked out which is suitable for the plotting sheet to be used. The two values A.M.T. and corresponding G.M.T. are then extracted from the top of the column and in the margin to the right of the setting longitude respectively. In the example given later in this chapter, the date is the night of September 30th-October 1st, and the setting longitude must lie between 11°E. and 25°E., these being the boundaries of the plotting sheet. The conversion table is then prepared, *before flight*, as follows. In the column headed W/Th 30/1, extract the setting longitude 20° 59′E, and corresponding G.M.T. 23.00 hours. At the top of the column extract A.M.T. 13.00 hours. Now since the G.M.T. time scale and A.M.T. time scale are the same size, once their relationships have been established by two corre-

sponding values, all the values for the rest of the night may be tabulated, and the following table should be drawn up ON THE PLOTTING SHEET TO WHICH IT REFERS. Remember that for every plotting sheet covering a different longitude belt, a new table is required, so the table should not be drawn in the navigation log.

<div align="center">

Sept. 30th-Oct. 1st.
Setting Long. 20° 59′E.

G.M.T.	A.M.T.
20.00	10.00
21.00	11.00
22.00	12.00
23.00	13.00
00.00	14.00
01.00	15.00
02.00	16.00

</div>

Astrograph Procedure.

13. The success of nearly all navigational work in the air is dependant on careful planning before flight. It is absolutely essential when using the astrograph to make careful pre-flight preparations to avoid unnecessary work at a time when every minute may be of vital importance.

14. *SEVERAL HOURS BEFORE FLIGHT.*

(a) Acquaintance should be made with details of the route and probable time of take-off, and the respective plotting sheets selected.

(b) Suppose the flight is to take place on the night of September 30th-October 1st, the route being from Norwich to Berlin, taking off at approximately 21.30 hours G.M.T. The plotting sheets required will be " North Sea " and " Germany." Part of the former is shown in Fig. 61.

(c) The limits of longitude of these two plotting sheets are 4° West to 11° East, and 11° East to 25° East respectively. Turn to the air almanac, and in the astrograph tables select the pages labelled September, and refer to the right-hand page, since this contains the data for east longitude (reproduced in Appendix A, Table 14).

Choose the correct date column, September 30th-October 1st, and select under this heading a suitable longitude for each plotting sheet, avoiding in doubtful cases the longitude opposite which a half hour value of G.M.T. is tabulated. The figures extracted for this example would be 5° 57′E. and 20° 59′E. for each plotting sheet respectively. Now extract the G.M.T. stated at the end of each line bearing these longitudes, and also the Time Addition at the top of the column, which is constant for all longitudes on a given night.

(*d*) Prepare each plotting sheet as in Fig. 61 with the above information. Mark the setting longitudes 5° 57′E. and 20° 59′E. on their respective plotting sheets by a meridian right down the sheet. State the information in words close to the setting longitude, and immediately below draw up the conversion table as explained in para. 12.

15. *JUST BEFORE FLIGHT*.

(*a*) Check the astrograph for serviceability and correct levelling. (See paras. 20 and 21.)

(*b*) Switch on lamp, and wind the film so that the correct latitude
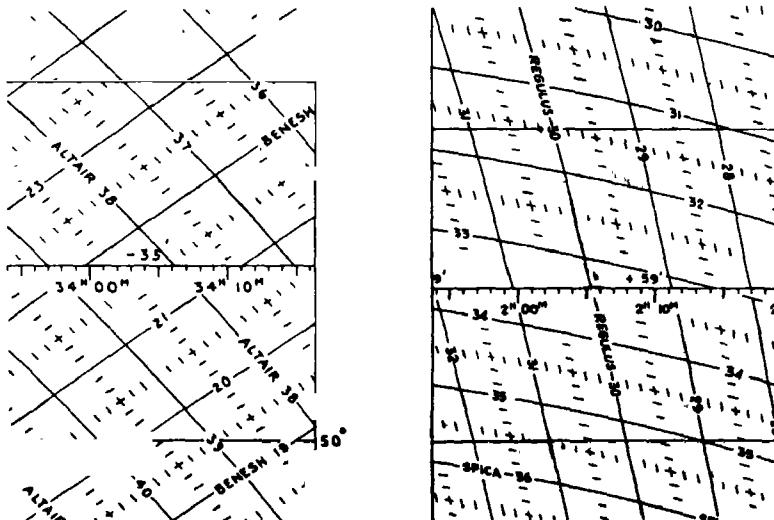
Fig. 60.

section is projected. Each film is subdivided into two or three separate sections, each section covering all plotting sheets having a certain latitude value. For a flight which changes longitude only, as in this example, one section of the film covers the whole flight, but in the case of a flight with a considerable change in latitude it may be necessary to jump from one section of the film to another by patiently turning the winding knob until the desired section is reached. It is even possible that a new film will be required altogether if the flight passes beyond the limits of latitude stated on each film. Two adjacent latitude sections of one film have been reproduced in Fig. 60.

(c) Having located the required latitude band, wind the film to bring the required A.M.T. for the start of the flight into position. With take-off time estimated at 21.30 hours, the film should be wound to 10.30 hours, being the corresponding A.M.T. extracted from the conversion table on the plotting sheet (Fig. 61).

(d) If necessary the plotting sheets should be cut to fit the navigation table rather than folding them, so that a true surface is ensured when they are pinned down. Any unevenness will cause an error in the position or scale of the projected curves.

16. *DURING FLIGHT.*

(a) Suppose it is required to fix the aircraft's position at about 22.45 hours G.M.T. Consult the conversion table on the first plotting sheet and read off the corresponding A.M.T.—11.45 hours. Switch on the astrograph and adjust the central traversing knob until the projected latitude lines coincide exactly with those on the plotting sheet. Wind the film to bring 11.45 hours on the time scale over the setting longitude meridian.

(b) In the region of the D.R. position of the aircraft, say 52°40'N, 07°20'E, read off the names and approximate altitudes of the two projected stars, in this case VEGA, altitude 36°, and DUBHE, altitude 25°. Should the star curves show a sudden jump from one star to another, such that it is not clear which is the correct curve, it is advisable to wait a few moments so that a slightly later time can be set on the film, and thus pass the point where a new star is commencing.
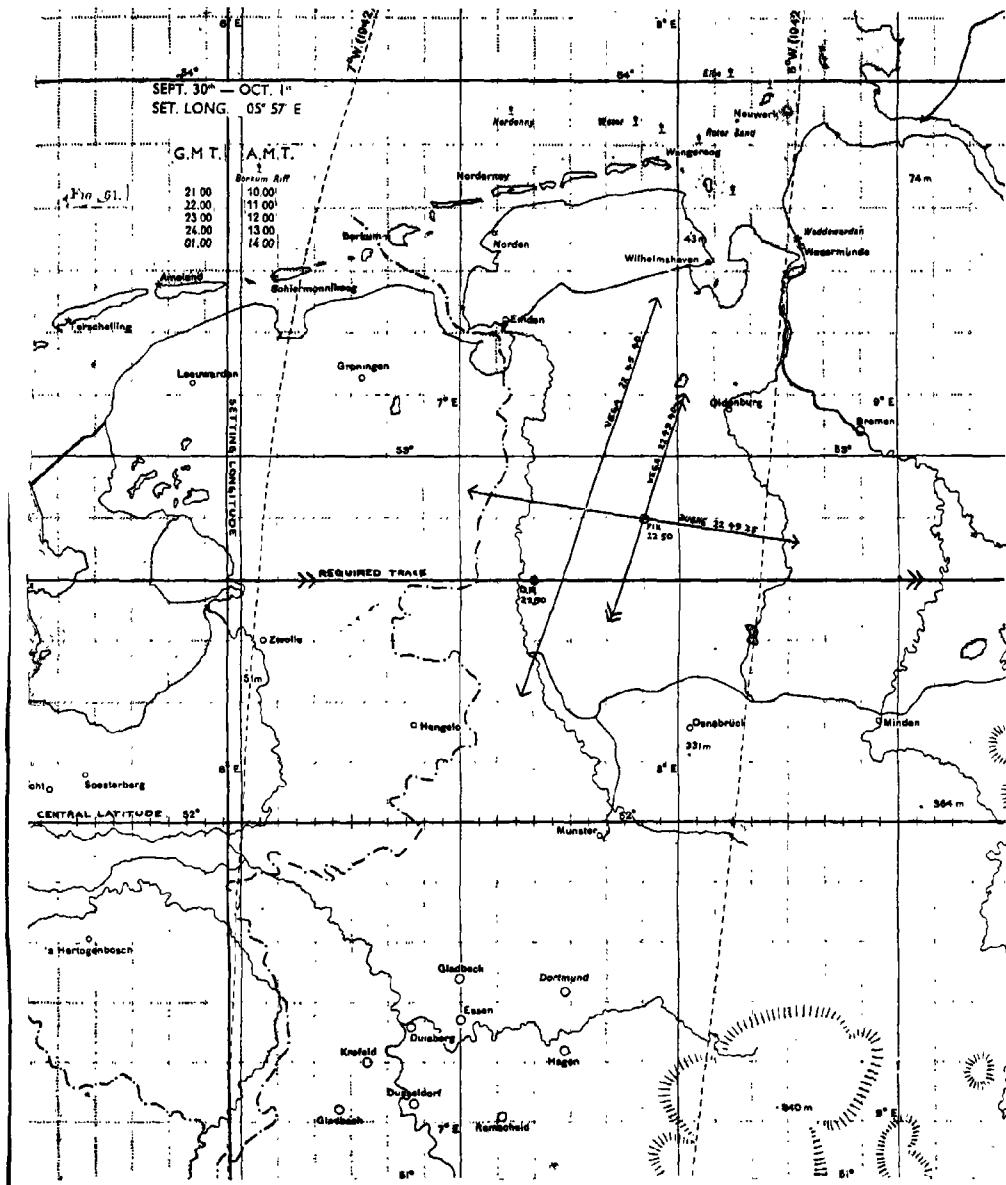
Fig. 61.

(c) Take the sextant and watch to the astro dome, and proceed to observe in the usual way. If any difficulty is experienced in star recognition, the approximate azimuths of the chosen stars are easily obtained from the astrograph, being in a direction at right angles to the star's curves, in the direction of increasing altitude. Thus with the approximate altitude and azimuth known, the required section of sky may be located without reference to other stars, a valuable feature when the sky is partly cloudy.

The following results are recorded :

Watch Reading	Correc-tion	G.M.T.	STAR	Sext. ALT.	Sext. Corr.	Dome Ref.	Obs. ALT.
22.45.30	10s	22.45.40	VEGA	35°59′	— 2′	— 5′	35°52′
22.49.25	10s	22.49.35	DUBHE	25°36′	— 2′	— 6′	25°28′

(d) Returning to the navigation table, switch on the astrograph, check that the projected latitude lines coincide accurately with the plotting sheet in the region of the D.R. position, and wind the film to bring 11.45.40 A.M.T. exactly on to the setting longitude meridian. (Interpolation for seconds on the time scale is carried out by eye.) Plot the star curve for Vega of 35°52′ in pencil parallel to the projected curves in the region of the D.R. position. Label the position line with arrow heads, and the words " Vega—22.46."

(e) REMEMBER TO WIND ON THE FILM to the second A.M.T., that of Dubhe—11.49.35. With this time exactly over the setting longitude, plot the Dubhe curve at 25°28′ altitude parallel to the projected curves, labelling the position line correctly " Dubhe—22.50."

(f) Switch off the astrograph, and lay in the aircraft's track line, say 090°T, in any convenient position to cut the first position line ; transfer this position line for 4 minutes at the ground speed, say 150 m.p.h., to allow for the aircraft's run between the observations. Label the transferred position line with double arrow heads, and the wording " Vega—22.50."

The point where the transferred position line for Vega cuts the position line for Dubhe is the aircraft's position at 22.50 G.M.T. (Fix—52°50′N, 07°50′E.)

17. *LATITUDE BY POLARIS.*

The addition of a polaris sight when making the observations will provide a third position line, and hence a cocked hat, which is a check on the accuracy of each sight.

The values for " Q " correction have been printed along the time scale of the astrograph film (Fig. 60), and since the film will be wound to the correct section in the process of plotting the other stars, the " Q " correction can be read off immediately, and the Polaris position line plotted at once.

The time of the sight should be converted to A.M.T. as before, and the A.M.T. set on the setting longitude meridian. The correct value of " Q " correction is then read off OPPOSITE THE LONGITUDE OF THE D.R. POSITION, in this case 07°20′E, and not opposite the setting longitude.

18. Notes.

(i) NEVER extend an astrograph position line by ruler after the astrograph has been switched off. The position line is a curve, and it can only be extended by winding the film back to the correct time and drawing it parallel to the star curves. Such a situation should be avoided by drawing the position lines in the region of the D.R. position, and the first one long enough to ensure a cut when transferred to the second.

(ii) Before experience has been gained, every possible use should be made of Polaris, obtaining the value of " Q " from the film. The whole procedure is without complication, and will soon accustom the navigator to working with the astrograph before attempting sights on the other stars.

(iii) All astrograph position lines MUST BE LABELLED with the name of the star and the time of observation immediately they are plotted. Without such a statement on the position line, immediately the astrograph is switched off or wound on, the line becomes a meaningless pencil mark, and if a second one is plotted, also without labelling, then the two are easily confused,

and the astrograph must be wound back and reset before the fix can be obtained.

(iv) Always state the date at the top of a G.M.T.-A.M.T. conversion table, in case the flight is cancelled for 24 hours or more, in which case a new table will be required. In all probability only the setting longitude will require alteration.

(v) If the astrograph is levelled and adjusted for height without touching the navigation table, care should be taken to avoid leaning heavily on the table while the position lines are being plotted, as the table may give a little, and thus increase the distance to the astrograph and cause a scale error in the curves.

Changing Films.

19. When the flight involves a considerable change in latitude, it is possible that two different films will be needed consecutively in order to cover the whole latitude band. The process of changing films is not easily carried out in the air, and in the event of such a situation arising, it would be wise to carry a second astrograph fitted with the second film, and simply change over astrographs when the transition is required. All astrographs are interchangeable, and once the mounting ring has been levelled for one instrument, then others may be clipped into position without re-levelling. (See para. 21.)

Fig. 62.

To change a film, first unscrew the six round-headed bolts on the face-plate (Fig. 62). The whole plate, spoolholders and film may then be

lifted out as a unit, leaving the top casting, lamp assembly and traversing mechanism. The unwanted film is wound off on to either spool as convenient, and removed by lifting it out squarely while the winding knob is pulled out. Select the new film, and draw out a length from the spool until the word " STOP " is visible. Place the spool holder section of the astrograph on the table with the face-plate downwards, and the WINDING KNOBS TOWARDS YOU. Ensure that the film is inserted the correct way round
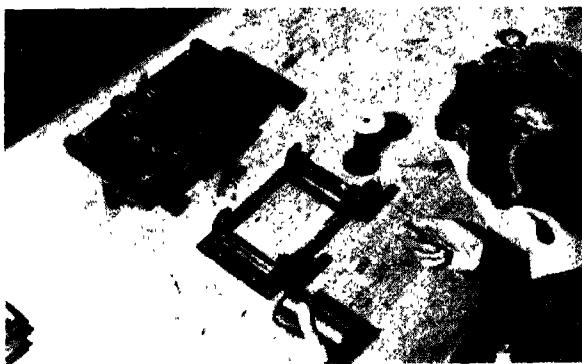
Fig. 63.

by remembering this one rule : With the spool holder positioned as above, the word " STOP " should appear the correct way up, and read from left to right (not " looking-glass " writing), as in Fig. 63. After the full spool has been inserted the film is slipped between the two glass plates and connected on to the empty spool. Give several turns on the winding knob to ensure that the film is running correctly before replacing the two halves of the instrument and screwing up the six round-headed bolts.

Electrical Notes.

20. The input supply for the astrograph is fed through one of two sockets labelled 12v. and 24v., with a red dummy plug to insert in the socket not being used. If there is doubt as to the voltage of the supply, a safe rule is to test the 24-volt socket first, and if the bulb only lights very dimly, then the supply plug may be transferred to the 12 volt socket.

Whether 12- or 24-volt, the supply is fed through a resistance where

the current is greatly reduced. This permits a specially designed lamp to be used which has a filament of very small dimensions, essential if a sharp image of the curves is to be thrown without any optical system whatever.

Accurate positioning of the lamp is most important, and it should be carried out so that the filament and side contact pins of the holder are all in the same plane, this being the correct distance between the lamp and film to show the curves at the correct scale for the plotting sheet. The filament should always be horizontal, so that the filament supports do not cut off any light.

The lamp assembly has been specially designed to meet these requirements, and the lamp is soldered in place to ensure that no alteration is made in the adjustment. No other type of lamp is suitable for the astrograph, since a normal filament gives a source of light that is too large, and the curves on the plotting sheet appear blurred and indistinct.

Mounting and Levelling.

21.   The astrograph is mounted in an aircraft by means of a rectangular mounting ring (Fig. 64), having three levelling bolts against which the astrograph is held under tension from the three spring-loaded support arms. The mounting ring is secured permanently to a fitting in the aircraft by means of bolts that may be inserted in a number of alternative positions giving a coarse preliminary height adjustment.

The wooden height gauge measures the distance between the navigation table and the under surface of each levelling bolt. These are adjusted with the spanner provided with the instrument, until the height rod just fits comfortably. The astrograph is then clipped into position and the supply plug from the aircraft fitted into the correct socket, as in para. 20.

Should any of the three spring-loaded arms of the astrograph be insufficiently tensioned when the instrument is in position, then it may sag, giving incorrect position lines

Fig. 64.

and vibrating during flight. If this should occur, the mounting ring must be unbolted from the aircraft and set one position higher. The height gauge is then used again and the levelling bolts screwed out to correct for the increased height of the ring. When the astrograph is refitted, the extended bolts will cause increased tension on the spring-loaded arms, thus holding the astrograph more firmly in place.

This point should always be inspected before flight by tapping the underneath of the astrograph to see if there is any movement.

Astrograph Films for Low Latitudes.

22. In Fig. 60 notice how " interpolating ticks " have been drawn between the star curves, to simplify plotting. On films which cover latitudes closer to the equator, the curves are closer together, since they are plotting on Mercator's projection just like the plotting sheets, and the interpolation ticks have been omitted from the films altogether.

Enclosed with the astrograph will be found an interpolating scale, which is used in such cases to increase the accuracy of plotting. The scale is placed across the two star curves adjacent to the required altitude, and adjusted until the readings fit the distance between the curves exactly. The required minutes of the altitude may then be counted along the scale, and the position line plotted in as before.

APPENDIX A.

Extracts from A.P. 1602—The Air Almanac
and A.P. 1618, Vol. L, The Astronomical
Navigation Tables.

STARS, SUN and PLANETS —　　　**OCT. 1, G.D. (THURSDAY)**

G.M.T.	G H A of First Point of ARIES = G.H.A.♈						G.M.T.	VENUS −3.4		JUPITER −1.7	
	00ᵐ	10ᵐ	20ᵐ	30ᵐ	40ᵐ	50ᵐ		G.H.A.	Dec.	G.H.A.	Dec.
h	° ′	° ′	° ′	° ′	° ′	° ′	h	° ′	° ′	° ′	° ′
00	9 06	11 36	14 06	16 37	19 07	21 38	00	192 51	N 3 12	254 52	N.21 37
01	24 08	26 38	29 09	31 39	34 10	36 40	01	207 51	3 11	269 54	21 37
02	39 11	41 41	44 11	46 42	49 12	51 43	02	222 50	3 09	284 56	21 37
03	54 13	56 43	59 14	61 44	64 15	66 45	03	237 50	3 08	299 58	21 37
04	69 15	71 46	74 16	76 47	79 17	81 48	04	252 50	3 07	315 00	21 37
05	84 18	86 48	89 19	91 49	94 20	96 50	05	267 49	N 3 06	330 02	N 21 37
06	99 20	101 51	104 21	106 52	109 22	111 52	06	282 49	3 05	345 05	21 37
07	114 23	116 53	119 24	121 54	124 25	126 55	07	297 48	3 03	0 07	21 37
08	129 25	131 56	134 26	136 57	139 27	141 57	08	312 48	3 02	15 09	21 37
09	144 28	146 58	149 29	151 59	154 29	157 00	09	327 48	3 01	30 11	21 37
10	159 30	162 01	164 31	167 01	169 32	172 02	10	342 47	N.3 00	45 13	N.21 37
11	174 33	177 03	179 34	182 04	184 34	187 05	11	357 47	2 58	60 15	21 36
12	189 35	192 06	194 36	197 06	199 37	202 07	12	12 46	2 57	75 17	21 36
13	204 38	207 08	209 38	212 09	214 39	217 10	13	27 46	2 56	90 19	21 36
14	219 40	222 11	224 41	227 11	229 42	232 12	14	42 46	2 55	105 22	21 36
15	234 43	237 13	239 43	242 14	244 44	247 15	15	57 45	N 2 53	120 24	N.21 36
16	249 45	252 15	254 46	257 16	259 47	262 17	16	72 45	2 52	135 26	21 36
17	264 48	267 18	269 48	272 19	274 49	277 20	17	87 44	2 51	150 28	21 36
18	279 50	282 20	284 51	287 21	289 52	292 22	18	102 44	2 50	165 30	21 36
19	294 52	297 23	299 53	302 24	304 54	307 24	19	117 44	2 49	180 32	21 36
20	309 55	312 25	314 56	317 26	319 57	322 27	20	132 43	N.2 47	195 34	N 21 36
21	324 57	327 28	329 58	332 29	334 59	337 29	21	147 43	2 46	210 37	21 36
22	340 00	342 30	345 01	347 31	350 01	352 32	22	162 42	2 45	225 39	21 36
23	355 02	357 33	0 03	2 34	5 04	7 34	23	177 42	2 44	240 41	21 36

G.M.T.	G.H.A. of SUN						SUN'S	G.M.T.	SATURN 0 2		Planets
	00ᵐ	10ᵐ	20ᵐ	30ᵐ	40ᵐ	50ᵐ	Dec		G H A	Dec.	
	° ′	° ′	° ′	° ′	° ′	° ′	° ′		° ′	° ′	
00	182 30	185 00	187 30	190 00	192 30	195 00	S.2 52	00	297 48	N.20 25	Mean S H A.
01	197 30	200 00	202 30	205 00	207 30	210 00	2 53	01	312 51	20 25	
02	212 30	215 00	217 30	220 00	222 30	225 00	2 54	02	327 53	20 25	V. 183
03	227 31	230 01	232 31	235 01	237 31	240 01	2 55	03	342 56	20 25	J. 246
04	242 31	245 01	247 31	250 01	252 31	255 01	2 55	04	357 58	20 25	s. 289
05	257 31	260 01	262 31	265 01	267 31	270 01	S.2 56	05	13 01	N 20 25	
06	272 31	275 01	277 31	280 01	282 31	285 01	2 57	06	28 03	20 25	360°
07	287 31	290 01	292 31	295 01	297 31	300 02	2 58	07	43 06	20 25	minus S H A
08	302 32	305 02	307 32	310 02	312 32	315 02	2 59	08	58 08	20 25	
09	317 32	320 02	324 32	325 02	327 32	330 02	3 00	09	73 11	20 25	V. 177
10	332 32	335 02	337 32	340 02	342 32	345 02	S.3 01	10	88 13	N 20 25	J. 114
11	347 32	350 02	352 32	355 02	357 32	0 02	3 02	11	103 16	20 25	s. 71
12	2 32	5 02	7 32	10 02	12 33	15 03	3 03	12	118 18	20 25	
13	17 33	20 03	22 33	25 03	27 33	30 03	3 04	13	133 21	20 25	Mer Pass
14	32 33	35 03	37 33	40 03	42 33	45 03	3 05	14	148 23	20 25	
15	47 33	50 03	52 33	55 03	57 33	60 03	S.3 06	15	163 26	N 20 25	h m V. 11 09
16	62 33	65 03	67 33	70 03	72 33	75 03	3 07	16	178 28	20 25	J. 07 00
17	77 33	80 03	82 33	85 03	87 34	90 04	3 08	17	193 31	20 25	s 04 08
18	92 34	95 04	97 34	100 04	102 34	105 04	3 09	18	208 33	20 25	
19	107 34	110 04	112 34	115 04	117 34	120 04	3 10	19	223 36	20 25	
20	122 34	125 04	127 34	130 04	132 34	135 04	S.3 11	20	238 38	N.20 25	Sun's S D
21	137 34	140 04	142 34	145 04	147 34	150 04	3 12	21	253 41	20 25	16′
22	152 34	155 04	157 34	160 04	162 35	165 05	3 13	22	268 43	20 25	
23	167 35	170 05	172 35	175 05	177 35	180 05	3 14	23	283 46	20 25	

Venus can be seen very low in the east at sunrise　Jupiter is bright and is well placed for observation in the east before sunrise　Saturn is most favourably placed for observation in the early morning, being in the east at midnight and in the west at sunrise.

Table 1.

◑ MOON — . . OCTOBER 1, G.D. (THURSDAY)

G.M.T.	00ᵐ G H A	Dec	10ᵐ G H A	Dec	20ᵐ G H A	Dec	P. in A	Lat	Twilight	Sunrise	Moonrise	Diff
h	° ′		° ′		° ′				h m	h m	h m	m
00	287 57	N.18 14	290 23	N 18 14	292 48	N 18 15	Alt.	N.68	05 16	06 10	19 37 20	
01	302 29	18 17	304 54	18 17	307 19	18 17	Corr.	66	05 19	06 08	20 08 21	
02	317 00	18 19	319 25	18 20	321 51	18 20	0 +	64	05 21	06 06	20 31 21	
03	331 31	18 22	333 57	18 22	336 22	18 22	9 54	62	05 22	06 05	20 49 22	
04	346 03	18 24	348 28	18 24	350 53	18 25	14 53					
05	0 34	N 18 26	2 59	N.18 27	5 24	N 18 27	18 52	N.60	05 23	06 03	21 05 22	
06	15 05	18 28	17 30	18 29	19 56	18 29	21 51	58	05 25	06 02	21 17 22	
07	29 37	18 30	32 02	18 31	34 27	18 31	24 50	56	05 25	06 01	21 28 22	
08	44 08	18 32	46 33	18 33	48 58	18 33	26 49	54	05 26	06 00	21 38 23	
09	58 39	18 34	61 04	18 35	63 30	18 35	28 48	52	05 27	05 59	21 47 23	
10	73 10	N 18 36	75 36	N.18 37	78 01	N.18 37	31 47	N.50	05 27	05 58	21 55 23	
11	87 42	18 38	90 07	18 38	92 32	18 39	32 46	45	05 28	05 57	22 11 23	
12	102 13	18 40	104 38	18 40	107 03	18 40	34 45	40	05 29	05 55	22 25 23	
13	116 44	18 41	119 09	18 41	121 35	18 42	36 44	35	05 29	05 54	22 37 23	
14	131 15	18 43	133 41	18 43	136 06	18 43	38 43	30	05 29	05 53	22 47 23	
15	145 47	N.18 44	148 12	N.18 44	150 37	N 18 45	40 42	N.20	05 29	05 51	23 04 24	
16	160 18	18 45	162 43	18 46	165 08	18 46	41 40	N.10	05 28	05 49	23 19 24	
17	174 49	18 47	177 14	18 47	179 39	18 47	43 39	0	05 26	05 47	23 34 24	
18	189 20	18 48	191 46	18 48	194 11	18 48	44 38	S.10	05 24	05 45	23 48 24	
19	203 52	18 49	206 17	18 49	208 42	18 49	46 37	S.20	05 20	05 43	(23 15)25	
							47 36					
20	218 23	N 18 50	220 48	N 18 50	223 13	N 18 50	49 35	S.30	05 15	05 40	(23 32)25	
21	232 54	18 51	235 19	18 51	237 44	18 51	50 34	35	05 12	05 39	(23 41)26	
22	247 25	18 52	249 50	18 52	252 16	18 52	51 33	40	05 09	05 37	(23 53)26	
23	261 56	18 52	264 22	18 52	266 47	18 52	53 32	45	05 04	05 35	00 06 26	
							54 31	S.50	04 58	05 32	00 22 27	

G.M.T.	30ᵐ G H A	Dec	40ᵐ G H A	Dec	50ᵐ G H A	Dec		Lat	Sunset	Twilight	Moonset	Diff
	° ′		° ′		° ′				h m	h m	h m	m
00	295 13	N.18 15	297 38	N.18 16	300 04	N.18 16	55 30	N.68	17 28	18 24	15 04 29	
01	309 44	18 18	312 10	18 18	314 35	18 19	57 29	66	17 29	18 21	14 33 28	
02	324 16	18 20	326 41	18 21	329 06	18 21	58 28	64	17 31	18 19	14 10 27	
03	338 47	18 23	341 12	18 23	343 37	18 24	59 27	62	17 33	18 18	13 52 27	
04	353 18	18 25	355 44	18 25	358 09	18 26	60 26					
05	7 50	N 18 27	10 15	N.18 28	12 40	N 18 28	61 26	N.60	17 35	18 17	13 37 27	
06	22 21	18 29	24 46	18 30	27 11	18 30	63 25	58	17 36	18 15	13 24 26	
07	36 52	18 31	39 17	18 32	41 43	18 32	64 24	56	17 38	18 15	13 13 26	
08	51 23	18 33	53 49	18 34	56 14	18 34	65 23	54	17 39	18 14	13 03 26	
09	65 55	18 35	68 20	18 36	70 45	18 36	66 22	52	17 40	18 13	12 55 26	
10	80 26	N.18 37	82 51	N.18 37	85 16	N.18 38	67 21	N.50	17 40	18 13	12 47 26	
11	94 57	18 39	97 22	18 39	99 48	18 39	68 20	45	17 42	18 12	12 30 25	
12	109 28	18 40	111 54	18 41	114 19	18 41	70 19	40	17 44	18 11	12 17 25	
13	124 00	18 42	126 25	18 42	128 50	18 42	71 18	35	17 45	18 11	12 06 25	
14	138 31	18 43	140 56	18 44	143 21	18 44	72 17	30	17 47	18 11	11 56 25	
15	153 02	N.18 45	155 27	N.18 45	157 53	N.18 45	73 16					
16	167 33	18 46	169 59	18 46	172 24	18 46	74 15	N.20	17 49	18 11	11 38 24	
17	182 05	18 47	184 30	18 47	186 55	18 48	75 14	N.10	17 51	18 12	11 23 24	
18	196 36	18 48	199 01	18 48	201 26	18 49	76 13	0	17 53	18 14	11 09 24	
19	211 07	18 49	213 32	18 50	215 58	18 50	77 12	S.10	17 56	18 16	10 55 23	
							78 11	S.20	17 58	18 20	10 40 23	
20	225 38	N.18 50	228 04	N 18 50	230 29	N.18 51	79 10					
21	240 10	18 51	242 35	18 51	245 00	18 51	80 9	S.30	18 01	18 25	10 23 23	
22	254 41	18 52	257 06	18 52	259 31	18 52		35	18 02	18 28	10 13 23	
23	269 12	18 53	271 37	18 53	274 02	18 53		40	18 04	18 31	10 01 22	
								45	18 07	18 36	09 48 22	
								S.50	18 09	18 42	09 31 21	

Phase of Moon—Last Quarter.   S.D. 15′   Meridian Passage 04 58 24

Figures in ( ) refer to the previous day as there is no moonrise from 00ʰ to 24ʰ on Greenwich meridian.

Table 2.

L

STARS, JULY — SEPT.

No	Name	Mag	SHA	Dec
1	ACHERNAR‡	0·6	336 06	S 57 32
2	ACRUX	1·1	174 09	S 62 47
3	ALDEBARAN‡	1·1	291 51	N.16 24
4	ALPHERATZ‡	2 2	358 39	N 28 46
5	ALTAIR	0·9	63 00	N. 8 43
6	ANTARES	1 2	113 32	S. 26 18
7	ARCTURUS	0·2	146 45	N 19 29
8	BETELGEUSE	*0·8	271 59	N. 7 24
9	CANOPUS	—0 9	264 20	S. 52 40
10	CAPELLA	0·2	281 54	N.45 56
11	DENEB	1 3	50 07	N 45 05
12	DUBHE	2·0	194 58	N 62 04
13	FOMALHAUT‡	1·3	16 23	S. 29 55
14	PEACOCK	2 1	54 43	S. 56 55
15	POLLUX	1·2	244 33	N 28 10
16	PROCYON	0·5	245 56	N. 5 22
17	REGULUS	1·3	208 41	N 12 15
18	RIGEL	0·3	282 04	S. 8 16
19	RIGEL KENT‡	0·1	141 05	S. 60 36
20	SIRIUS	—1·6	259 21	S 16 38
21	SPICA	1·2	159 28	S. 10 52
22	VEGA	0·1	81 15	N 38 44
23	Adara	1·6	255 55	S 28 54
24	Alhena	1·9	261 24	N 16 27
25	Alnilak	1·9	275 32	S 1 58
26	Alphacca	2·3	126 56	N.26 55
27	Alphard	2 2	218 49	S. 8 24
28	Antlam	1·8	276 41	S. 1 14
29	Bellatrix	1·7	279 29	N. 6 18
30	Denebola	2·2	183 28	N.14 54
31	Diphda	2·2	349 49	S 18 18
32	Hamal	2·2	329 01	N 23 11
33	Nath	1 8	279 20	N.28 33
34	Ras Alhague	2·1	96 56	N 12 36
35	Wezen	2 0	253 29	S 26 18
36	Alioth	1·7	167 08	N 56 17
37	γ Argus	1·9	238 04	S 47 10
38	Avior§	1·7	234 40	S. 59 19
39	Benetnasch‡	1·9	153 41	N.49 36
40	Castor	1·6	247 16	N.32 01
41	β Centauri	0·9	150 04	S.60 06
42	β Crucis	1·5	168 55	S. 59 23
43	γ Crucis	1·6	173 01	S 56 48
44	Kaus Aust	2·0	84 55	S 34 25
45	Miaplacidus	1·8	221 52	S 69 29
46	Mirfak	1 9	309 57	N.49 39
47	Polaris	2·1	333 46	N.88 59
48	Schedar	†2·3	350 41	N.56 13
49	Shaula	1·7	97 34	S 37 04
50	α Tri. Aust	1·9	109 21	S 68 56

STANDARD DOME REFRACTION

Subtract from the obs. alt. when using sextant suspension in a perspex dome. (Not to be used if a calibration table or a flat glass plate is provided.)

Alt. Refn		Alt Refn
10	8	50 4
20	7	60 4
30	6	70 3
40	5	80 3

BUBBLE SEXTANT

(No)

Alt Corrn		Alt Corrn
10		50
20		60
30		70
40		80

DIP

Subtract from the obs alt (marine sextant)

Ht Dip		Ht Dip
Ft		Ft.
0	0	395 20
2	1	437
6	2	481 21
12	3	527 22
21	4	575 23
31	5	625 24
43	6	677 25
58	7	731 26
75	8	787 27
93	9	845 28
114	10	906 29
137	11	968 30
162	12	1033 31
189	13	1099 32
218	14	1168 33
250	15	1239 34
283	16	1311 35
318	17	1386 36
356	18	1463 37
395	19	1543 38

MARINE SEXTANT

(No)

Index Error

INTERPOLATION OF G.H.A.♈ AND G.H.A. SUN

Increment to be added to G.H.A of Aries and Sun for intervals of G.M.T.

m s	° ′	m s	° ′	m s	° ′
00 00	0 00	03 17	0 50	06 37	1 40
01	0 01	21	0 51	41	1 41
05	0 02	25	0 52	45	1 42
09	0 03	29	0 53	49	1 43
13	0 04	33	0 54	53	1 44
17	0 05	37	0 55	06 57	1 45
21	0 06	41	0 56	07 01	1 46
25	0 07	45	0 57	05	1 47
29	0 08	49	0 58	09	1 48
33	0 09	53	0 59	13	1 49
37	0 10	03 57	1 00	17	1 50
41	0 11	04 01	1 01	21	1 51
45	0 12	05	1 02	25	1 52
49	0 13	09	1 03	29	1 53
53	0 14	13	1 04	33	1 54
00 57	0 15	17	1 05	37	1 55
01 01	0 16	21	1 06	41	1 56
05	0 17	25	1 07	45	1 57
09	0 18	29	1 08	49	1 58
13	0 19	33	1 09	53	1 59
17	0 20	37	1 10	07 57	1 59
21	0 21	41	1 11	08 01	2 00
25	0 22	45	1 12	05	2 01
29	0 23	49	1 13	09	2 02
33	0 24	53	1 14	13	2 03
37	0 25	04 57	1 15	17	2 04
41	0 26	05 01	1 16	21	2 05
45	0 27	05	1 17	25	2 06
49	0 28	09	1 18	29	2 07
53	0 29	13	1 19	33	2 08
01 57	0 30	17	1 20	37	2 09
02 01	0 31	21	1 21	41	2 10
05	0 32	25	1 22	45	2 11
09	0 33	29	1 23	49	2 12
13	0 34	33	1 24	53	2 13
17	0 35	37	1 25	08 57	2 14
21	0 36	41	1 26	09 01	2 15
25	0 37	45	1 27	05	2 16
29	0 38	49	1 28	09	2 17
33	0 39	53	1 29	13	2 18
37	0 40	05 57	1 30	17	2 19
41	0 41	06 01	1 31	21	2 20
45	0 42	05	1 31	25	2 21
49	0 43	09	1 32	29	2 22
53	0 44	13	1 33	33	2 23
02 57	0 45	17	1 34	37	2 24
03 01	0 46	21	1 35	41	2 25
05	0 47	25	1 36	45	2 26
09	0 48	29	1 37	49	2 27
13	0 49	33	1 38	53	2 28
17	0 49	37	1 39	09 57	2 29
03 21	0 50	06 41	1 40	10 00	2 30

When the argument is an exact tabulated value, the *upper* of the two possible values of the result should be taken

* BETELGEUSE, variable magnitude 0 5–1·1   † *Schedar*, variable magnitude 2·1–2 6   § ‹ Argus
‡ The following abbreviations are used in the Astrograph —
No 1 ACHAR No 3 ALDEBAN No 4 ALPHAZ No. 13 FOMALT No 19 RIKENT No 19 BENESH

Table 3.

INTERPOLATION OF G.H.A. MOON

Increment to be added to G.H A of the Moon for intervals of G.M T.

m s	° '	m s	° '	m s	° '
00 00	0 00	03 20	0 49	06 39	1 37
02	0 01	24	0 50	43	1 38
06	0 02	29	0 51	47	1 39
10	0 03	33	0 52	51	1 40
14	0 04	37	0 53	06 56	1 41
18	0 05	41	0 54	07 00	1 42
22	0 06	45	0 55	04	1 43
26	0 07	49	0 56	08	1 44
31	0 08	53	0 57	12	1 45
35	0 09	03 58	0 58	16	1 46
39	0 10	04 02	0 59	20	1 47
43	0 11	06	1 00	25	1 48
47	0 12	10	1 01	29	1 49
51	0 13	14	1 02	33	1 50
00 55	0 14	18	1 03	37	1 51
01 00	0 15	22	1 04	41	1 52
04	0 16	27	1 05	45	1 53
08	0 17	31	1 06	49	1 54
12	0 18	35	1 07	54	1 55
16	0 19	39	1 08	07 58	1 56
20	0 20	43	1 09	08 02	1 57
24	0 21	47	1 10	06	1 58
29	0 22	51	1 11	10	1 59
33	0 23	04 56	1 12	14	2 00
37	0 24	05 00	1 13	18	2 01
41	0 25	04	1 14	23	2 02
45	0 26	08	1 15	27	2 03
49	0 27	12	1 16	31	2 04
53	0 28	16	1 17	35	2 05
01 57	0 29	20	1 18	39	2 06
02 02	0 30	25	1 19	43	2 07
06	0 31	29	1 20	47	2 08
10	0 32	33	1 21	52	2 09
14	0 33	37	1 22	08 56	2 10
18	0 34	41	1 23	09 00	2 11
22	0 35	45	1 24	04	2 12
26	0 36	49	1 25	08	2 13
31	0 37	53	1 26	12	2 14
35	0 38	05 58	1 27	16	2 15
39	0 39	06 02	1 28	20	2 16
43	0 40	06	1 29	25	2 17
47	0 41	10	1 30	29	2 18
51	0 42	14	1 31	33	2 19
02 55	0 43	18	1 32	37	2 20
03 00	0 44	22	1 33	41	2 21
04	0 45	27	1 34	45	2 22
08	0 46	31	1 35	49	2 23
12	0 47	35	1 36	54	2 24
16	0 48	39	1 37	09 58	2 25
03 20		06 43		10 00	

When the argument is an exact tabulated value, the *upper* of the two possible values of the result should be taken

STANDARD DOME REFRACTION

Subtract from the obs. alt. when using sextant suspension in a perspex dome. (Not to be used if a calibration table or a flat glass plate is provided)

Alt.	Refn	Alt.	Refn
°	'	°	'
10	8	50	4
20	7	60	4
30	6	70	3
40	5	80	3

BUBBLE SEXTANT

(No)

Alt.	Corrn	Alt.	Corrn
°	'	°	'
10		50	
20		60	
30		70	
40		80	

DIP

Subtract from the obs. alt (marine sextant)

Ht.	Dip	Ht	Dip
Ft.	'	Ft	'
0	1	395	20
2	2	437	21
6	3	481	22
12	4	527	23
21	5	575	24
31	6	625	25
43	7	677	26
58	8	731	27
75	9	787	28
93	10	845	29
114	11	906	30
137	12	968	31
162	13	1033	32
189	14	1099	33
218	15	1168	34
250	16	1239	35
283	17	1311	36
318	18	1386	37
356	19	1463	38
395		1543	

MARINE SEXTANT

(No)

Index Error

INTERPOLATION OF MOONRISE, ETC. FOR LONGITUDE

Longitude	Diff					
	5	10	15	20	25	30
°	m	m	m	m	m	m
0	00	00	00	00	00	00
10	00	01	01	01	01	02
20	01	01	02	02	03	03
30	01	02	02	03	04	05
40	01	02	03	04	06	07
50	01	03	04	06	07	08
60	02	03	05	07	08	10
70	02	04	06	08	10	12
80	02	04	07	09	11	13
90	02	05	08	10	12	15
100	03	06	08	11	14	17
110	03	06	09	12	15	18
120	03	07	10	13	17	20
130	04	07	11	14	18	22
140	04	08	12	16	19	23
150	04	08	12	17	21	25
160	04	09	13	18	22	27
170	05	09	14	19	24	28
180	05	10	15	20	25	30

Longitude	Diff					
	35	40	45	50	55	60
°	m	m	m	m	m	m
0	00	00	00	00	00	00
10	02	02	02	03	03	03
20	04	04	05	06	06	07
30	06	07	08	08	09	10
40	08	09	10	11	12	13
50	10	11	12	14	15	17
60	12	13	15	17	18	20
70	14	16	18	19	21	23
80	16	18	20	22	24	27
90	18	20	22	25	28	30
100	19	22	25	28	31	33
110	21	24	28	31	34	37
120	23	27	30	33	37	40
130	25	29	32	36	40	43
140	27	31	35	39	43	47
150	29	33	38	42	46	50
160	31	36	40	44	49	53
170	33	38	42	47	52	57
180	35	40	45	50	55	60

The above table with arguments *Diff* and longitude gives the correction that must be applied to the times of moonrise, moonset and the Moon's meridian passage to obtain the L M T of these phenomena in longitudes other than Greenwich. The correction is to be *added* if longitude is *west*, *subtracted* if longitude is *east*.

Table 4.

INTERPOLATION OF G.H.A. PLANETS

32 01		36 01		40 00		44 00		48 03		52 03		56 02	
05	8 02	05	9 02	04	10 02	04	11 02	07	12 03	07	13 03	06	14 03
09	8 03	09	9 03	08	10 03	08	11 03	11	12 04	11	13 04	10	14 04
13	8 04	13	9 04	12	10 04	12	11 04	15	12 05	15	13 05	14	14 05
17	8 05	17	9 05	16	10 05	16	11 05	19	12 06	19	13 06	18	14 06
21	8 06	21	9 06	20	10 06	20	11 06	23	12 07	23	13 07	22	14 07
25	8 07	25	9 07	24	10 07	24	11 07	27	12 08	27	13 08	26	14 08
29	8 08	29	9 08	28	10 08	28	11 08	31	12 09	30	13 09	30	14 09
33	8 09	33	9 09	32	10 09	32	11 09	35	12 10	34	13 10	34	14 10
37	8 10	37	9 10	36	10 10	36	11 10	39	12 11	38	13 11	38	14 11
41	8 11	41	9 11	40	10 11	40	11 11	43	12 12	42	13 12	42	14 12
45	8 12	45	9 12	44	10 12	44	11 12	47	12 13	46	13 13	46	14 13
49	8 13	49	9 13	48	10 13	48	11 13	51	12 14	50	13 14	50	14 14
53	8 14	53	9 14	52	10 14	52	11 14	55	12 15	54	13 15	54	14 15
32 57	8 15	36 57	9 15	40 56	10 15	56	11 15	48 59	12 16	52 58	13 16	56 58	14 16
	8 16		9 16		10 16	44 59	11 16		12 17		13 17		14 17
							11 17						
33 01	8 17	37 01	9 17	41 00	10 17	45 03	11 18	49 03	12 18	53 02	13 18	57 02	14 18
05	8 18	05	9 18	04	10 18	07	11 19	07	12 19	06	13 19	06	14 19
09	8 19	09	9 19	08	10 19	11	11 20	11	12 20	10	13 20	10	14 20
13	8 20	13	9 20	12	10 19	15	11 21	15	12 21	14	13 21	14	14 21
17	8 21	17	9 21	16	10 20	19	11 22	19	12 22	18	13 22	18	14 22
21	8 22	21	9 22	20	10 21	23	11 23	23	12 23	22	13 23	22	14 23
25	8 23	25	9 23	24	10 22	27	11 24	27	12 24	26	13 24	26	14 24
29	8 24	29	9 24	28	10 23	31	11 25	31	12 25	30	13 25	30	14 25
33	8 25	32	9 25	32	10 24	35	11 26	35	12 26	34	13 26	34	14 26
37	8 26	36	9 26	36	10 25	39	11 27	39	12 27	38	13 27	38	14 27
41	8 27	40	9 27	40	10 26	43	11 28	43	12 28	42	13 28	42	14 28
45	8 28	44	9 28	44	10 27	47	11 29	47	12 29	46	13 29	46	14 29
49	8 29	48	9 29	48	10 28	51	11 30	51	12 30	50	13 30	50	14 30
53	8 30	52	9 30	52	10 29	55	11 31	55	12 31	54	13 31	54	14 31
33 57	8 31	37 56	9 30	41 56	10 30	45 59	11 32	49 59	12 32	53 58	13 32	57 58	14 32
			9 31		10 31								
34 01	8 32	38 00	9 32	42 00	10 32	46 03	11 33	50 03	12 33	54 02	13 33	58 02	14 33
05	8 33	04	9 33	04	10 33	07	11 34	07	12 34	06	13 34	06	14 34
09	8 34	08	9 34	08	10 33	11	11 34	11	12 34	10	13 34	10	14 34
13	8 34	12	9 34	12	10 34	15	11 35	15	12 35	14	13 35	14	14 35
17	8 35	16	9 35	16	10 35	19	11 36	19	12 36	18	13 36	18	14 36
21	8 36	20	9 36	20	10 36	23	11 37	23	12 37	22	13 37	22	14 37
25	8 37	24	9 37	24	10 37	27	11 38	27	12 38	26	13 38	26	14 38
29	8 38	28	9 38	28	10 38	31	11 39	31	12 39	30	13 39	30	14 39
33	8 39	32	9 39	32	10 39	35	11 40	35	12 40	34	13 40	34	14 40
37	8 40	36	9 40	36	10 40	39	11 41	39	12 41	38	13 41	38	14 41
41	8 41	40	9 41	40	10 41	43	11 42	43	12 42	42	13 42	42	14 42
45	8 42	44	9 42	44	10 42	47	11 43	47	12 43	46	13 43	46	14 43
49	8 43	48	9 43	48	10 43	51	11 44	51	12 44	50	13 44	50	14 44
53	8 44	52	9 44	52	10 44	55	11 45	55	12 45	54	13 45	54	14 45
34 57	8 45	38 56	9 45	42 56	10 45	46 59	11 46	50 59	12 46	54 58	13 46	58 58	14 46
	8 46		9 46		10 46		11 47		12 47		13 47		14 47
35 01	8 47	39 00	9 47	43 00	10 47	47 03	11 48	51 03	12 48	55 02	13 48	59 02	14 48
05	8 48	04	9 48	04	10 48	07	11 49	07	12 49	06	13 49	06	14 49
09	8 49	08	9 49	08	10 49	11	11 50	11	12 50	10	13 50	10	14 50
13	8 50	12	9 50	12	10 49	15	11 51	15	12 51	14	13 51	14	14 51
17	8 51	16	9 51	16	10 50	19	11 51	19	12 51	18	13 51	18	14 51
21	8 52	20	9 52	20	10 51	23	11 52	23	12 52	22	13 52	22	14 52
25	8 52	24	9 52	24	10 52	27	11 53	27	12 53	26	13 53	26	14 53
29	8 53	28	9 53	28	10 53	31	11 54	31	12 54	30	13 54	30	14 54
33	8 54	32	9 54	32	10 54	35	11 55	35	12 55	34	13 55	34	14 55
37	8 55	36	9 55	36	10 55	39	11 56	39	12 56	38	13 56	38	14 56
41	8 56	40	9 56	40	10 56	43	11 57	43	12 57	42	13 57	42	14 57
45	8 57	44	9 57	44	10 57	47	11 58	47	12 58	46	13 58	46	14 58
49	8 58	48	9 58	48	10 58	51	11 59	51	12 59	50	13 59	50	14 59
53	8 59	52	9 59	52	10 59	55	12 00	55	13 00	54	14 00	54	15 00
	9 00		10 00		11 00		12 01		13 01		14 01		15 01
35 57	9 01	39 56	10 01	43 56	11 01	47 59	12 02	51 59	13 02	55 58	14 02	59 58	15 02
36 01		40 00		44 00		48 03		52 03		56 02		60 00	

When the argument is an exact tabulated value, the *upper* of the two possible values of the result should be taken

Table 5.

POLE STAR TABLE,

FOR DETERMINING THE LATITUDE FROM AN OBSERVED ALTITUDE

L.H.A ♈	Q	L.H.A ♈	Q	L.H.A ♈	Q	L.H.A ♈	Q	L.H.A ♈	Q	L.H.A ♈	Q	L.H.A ♈	Q
358 25	−55	82 06	−34	117 01	+ 1	152 46	+36	239 52	+49	281 46	+14	315 22	−21
0 30	−56	83 13	−33	117 58	+ 2	153 59	+37	241 34	+48	282 45	+13	316 22	−22
2 44	−57	84 20	−32	118 55	+ 3	155 12	+38	243 11	+47	283 43	+12	317 23	−23
5 13	−58	85 26	−31	119 52	+ 4	156 27	+39	244 45	+46	284 41	+11	318 23	−24
8 00	−58	86 31	−30	120 49	+ 5	157 43	+40	246 16	+45	285 39	+10	319 24	−25
11 17	−59	87 35	−29	121 46	+ 6	159 00	+41	247 44	+44	286 37	+ 9	320 26	−26
15 31	−60	88 39	−28	122 43	+ 7	160 20	+42	249 09	+43	287 35	+ 8	321 28	−27
23 49	−61	89 42	−27	123 41	+ 8	161 41	+43	250 32	+42	288 32	+ 7	322 31	−28
28 24	−62	90 45	−26	124 38	+ 9	163 04	+44	251 53	+41	289 30	+ 6	323 34	−29
36 42	−61	91 47	−25	125 36	+10	164 29	+45	253 13	+40	290 27	+ 5	324 38	−30
40 56	−60	92 49	−24	126 34	+11	165 57	+46	254 30	+39	291 24	+ 4	325 42	−31
44 13	−59	93 50	−23	127 32	+12	167 28	+47	255 46	+38	292 21	+ 3	326 47	−32
47 00	−58	94 50	−22	128 30	+13	169 02	+48	257 01	+37	293 18	+ 2	327 53	−33
49 29	−57	95 51	−21	129 28	+14	170 39	+49	258 14	+36	294 15	+ 1	329 00	−34
51 43	−56	96 51	−20	130 27	+15	172 21	+50	259 27	+35	295 12	0	330 07	−35
53 48	−55	97 50	−19	131 26	+16	174 07	+51	260 38	+34	296 08	− 1	331 15	−36
55 45	−54	98 50	−18	132 25	+17	175 58	+52	261 47	+33	297 05	− 2	332 25	−37
57 35	−53	99 49	−17	133 25	+18	177 57	+53	262 56	+32	298 02	− 3	333 35	−38
59 19	−52	100 47	−16	134 25	+19	180 03	+54	264 04	+31	298 59	− 4	334 46	−39
60 59	−51	101 46	−15	135 25	+20	182 20	+55	265 12	+30	299 56	− 5	335 59	−40
62 35	−50	102 44	−14	136 26	+21	184 51	+56	266 18	+29	300 52	− 6	337 12	−41
64 08	−49	103 42	−13	137 27	+22	187 41	+57	267 24	+28	301 49	− 7	338 28	−42
65 37	−48	104 40	−12	138 29	+23	191 02	+58	268 29	+27	302 46	− 8	339 44	−43
67 04	−47	105 38	−11	139 31	+24	195 20	+59	269 33	+26	303 43	− 9	341 03	−44
68 29	−46	106 35	−10	140 33	+25	203 49	+60	270 37	+25	304 41	−10	342 23	−44
69 50	−45	107 32	− 9	141 36	+26	208 24	+59	271 40	+24	305 38	−11	343 44	−45
71 10	−44	108 30	− 8	142 40	+27	216 53	+58	272 42	+23	306 35	−12	345 09	−46
72 29	−43	109 27	− 7	143 44	+28	221 11	+57	273 44	+22	307 33	−13	346 36	−47
73 45	−42	110 24	− 6	144 49	+29	224 32	+56	274 46	+21	308 31	−14	348 05	−48
75 01	−41	111 21	− 5	145 55	+30	227 22	+55	275 47	+20	309 29	−15	349 38	−49
76 14	−40	112 17	− 4	147 01	+31	229 53	+54	276 48	+19	310 27	−16	351 14	−50
77 27	−39	113 14	− 3	148 09	+32	232 10	+54	277 48	+18	311 26	−17	352 54	−51
78 38	−38	114 11	− 2	149 17	+33	234 16	+53	278 48	+18	312 24	−18	354 38	−52
79 48	−37	115 08	− 1	150 26	+34	236 15	+52	279 48	+17	313 23	−19	356 28	−53
80 58	−36	116 05	0	151 35	+34	238 06	+51	280 47	+16	314 23	−20	358 25	−54
82 06	−35	117 01	0	152 46	+35	239 52	+50	281 46	+15	315 22	−20	0 30	−55

When the argument is an exact tabulated value, the *upper* of the two possible values of the result should be taken

Table 6.

3°   DECLINATION **CONTRARY** NAME TO LATITUDE   **3°**

LAT.	50°		51°		52°		53°		54°		LAT.
H.A.	Alt.	Az.	Alt.	Az.	Alt.	Az.	Alt.	Az.	Alt.	Az.	H.A.
	° ′ d	°	° ′ d	°	° ′ d	°	° ′ d	°	° ′ d	°	°
0	37 01-60	180	36 01-60	180	35 01-60	180	34 01-60	180	33 01-60	180	360
1	37 01 60	179	36 01 60	179	35 01 60	179	34 01 60	179	33 01 60	179	359
2	36 59 60	178	35 59 59	178	35 00 60	178	34 00 60	178	33 00 60	178	358
3	36 57 60	176	35 57 59	176	34 58 60	176	33 58 60	176	32 58 60	176	357
4	36 54 60	175	35 55 60	175	34 55 60	175	33 55 60	175	32 55 59	175	356
5	36 51-60	174	35 51-60	174	34 51-59	174	33 52-60	174	32 52-60	174	355
6	36 46 60	173	35 47 60	173	34 47 60	173	33 48 60	173	32 48 60	173	354
7	36 41 60	171	35 41 59	171	34 42 60	171	33 43 60	172	32 43 59	172	353
8	36 34 59	170	35 35 59	170	34 36 59	170	33 37 60	170	32 38 60	171	352
9	36 27 59	169	35 28 59	169	34 30 60	169	33 31 60	169	32 32 60	169	351
10	36 19-59	168	35 21-60	168	34 22-59	168	33 24-60	168	32 25-60	168	350
11	36 11 60	166	35 12 59	167	34 14 59	167	33 16 60	167	32 17 59	167	349
12	36 01 59	165	35 03 59	165	34 05 59	165	33 07 59	166	32 09 60	166	348
13	35 51 59	164	34 53 59	164	33 56 60	164	32 58 59	164	32 00 59	165	347
14	35 40 59	163	34 42 58	163	33 45 59	163	32 48 59	163	31 50 59	163	346
15	35 28-59	162	34 31-59	162	33 34-59	162	32 37-59	162	31 40-59	162	345
16	35 15 58	160	34 19 59	161	33 22 58	161	32 26 59	161	31 29 59	161	344
17	35 02 58	159	34 06 59	159	33 10 59	160	32 14 59	160	31 17 59	160	343
18	34 48 58	158	33 52 58	158	32 57 59	158	32 01 59	159	31 05 59	159	342
19	34 33 58	157	33 38 58	157	32 43 59	157	31 47 58	158	30 52 59	158	341
20	34 17-57	156	33 23-58	156	32 28-58	156	31 33-58	156	30 38-58	157	340
21	34 01 57	154	33 07 58	155	32 13 58	155	31 18 58	155	30 24 58	155	339
22	33 44 57	153	32 51 58	154	31 57 58	154	31 03 58	154	30 09 58	154	338
23	33 26 57	152	32 33 57	152	31 40 57	153	30 47 58	153	29 53 57	153	337
24	33 08 57	151	32 16 58	151	31 23 57	152	30 30 57	152	29 37 57	152	336
25	32 49-57	150	31 57-57	150	31 05-57	150	30 13-57	151	29 20-57	151	335
26	32 29 56	149	31 38 57	149	30 47 57	149	29 55 57	150	29 03 57	150	334
27	32 09 56	148	31 18 56	148	30 28 57	148	29 36 57	149	28 45 57	149	333
28	31 48 56	147	30 58 56	147	30 08 57	147	29 17 56	147	28 27 57	148	332
29	31 27 56	145	30 37 56	146	29 48 57	146	28 58 57	146	28 08 57	147	331
30	31 04-55	144	30 16-56	145	29 27-56	145	28 37-56	145	27 48-57	146	330
31	30 42 56	143	29 54 56	144	29 05 56	144	28 17 56	144	27 28 56	145	329
32	30 18 55	142	29 31 55	143	28 43 55	143	27 55 56	143	27 07 56	144	328
33	29 54 54	141	29 08 55	142	28 21 56	142	27 33 55	142	26 46 56	142	327
34	29 30 55	140	28 44 55	140	27 58 56	141	27 11 55	141	26 24 55	141	326
35	29 05-54	139	28 20-55	139	27 34-55	140	26 48-55	140	26 02-55	140	325
36	28 40 55	138	27 55 55	138	27 10 55	139	26 25 55	139	25 39 55	139	324
37	28 14 54	137	27 30 55	137	26 45 54	138	26 01 55	138	25 16 55	138	323
38	27 47 54	136	27 04 54	136	26 20 54	137	25 37 55	137	24 53 55	137	322
39	27 20 53	135	26 38 54	135	25 55 54	136	25 12 55	136	24 29 55	136	321
40	26 53-54	134	26 11-54	134	25 29-54	135	24 46-54	135	24 04-55	135	320
41	26 25 53	133	25 44 54	133	25 02 53	134	24 21 54	134	23 39 54	134	319
42	25 56 52	132	25 16 53	132	24 35 53	133	23 55 54	133	23 14 55	133	318
43	25 27 52	131	24 48 53	131	24 08 53	132	23 28 54	132	22 48 54	132	317
44	24 58 52	130	24 19 52	130	23 40 53	131	23 01 53	131	22 22 54	131	316
45	24 28-52	129	23 50-52	129	23 12-53	130	22 34-53	130	21 55-54	130	315

In North { For argument H.A. on the left, True Azimuth = 360° − Tabulated Azimuth. } See
Latitudes { For argument H.A. on the right, True Azimuth = Tabulated Azimuth. } p 90.

Table 7.

18° DECLINATION **SAME** NAME AS LATITUDE **18°**

H.A.	50° Alt.	Az.	51° Alt.	Az.	52° Alt.	Az.	53° Alt.	Az.	54° Alt.	Az.	H.A.
0	58 01+59	180	57 01+60	180	56 01+60	180	55 01+60	180	54 01+60	180	360
1	58 00 60	178	57 00 60	178	56 00 60	178	55 00 60	178	54 00 60	178	359
2	57 58 60	176	56 58 60	177	55 58 60	177	54 58 60	177	53 59 60	177	358
3	57 55 60	175	56 55 60	175	55 56 60	175	54 56 60	175	53 56 60	175	357
4	57 51 60	173	56 51 60	173	55 52 60	173	54 52 60	173	53 53 59	174	356
5	57 45+60	171	56 46+60	171	55 47+60	172	54 48+59	172	53 48+60	172	355
6	57 39 59	169	56 40 59	170	55 41 59	170	54 42 59	170	53 43 59	170	354
7	57 31 59	168	56 33 59	168	55 34 59	168	54 35 60	168	53 36 60	169	353
8	57 22 59	166	56 24 59	166	55 26 59	167	54 27 60	167	53 29 59	167	352
9	57 12 59	164	56 15 59	164	55 17 59	165	54 19 59	165	53 21 59	166	351
10	57 01+59	162	56 04+59	163	55 07+58	163	54 09+59	164	53 11+60	164	350
11	56 49 58	161	55 52 59	161	54 55 59	162	53 58 59	162	53 01 59	162	349
12	56 36 58	159	55 39 59	159	54 43 59	160	53 47 58	160	52 50 59	161	348
13	56 21 58	157	55 26 58	158	54 30 58	158	53 34 59	159	52 38 59	159	347
14	56 06 57	156	55 11 58	156	54 16 58	157	53 21 58	157	52 25 59	158	346
15	55 49+58	154	54 55+58	155	54 01+58	155	53 06+58	156	52 12+58	156	345
16	55 32 57	152	54 39 57	153	53 45 57	153	52 51 58	154	51 57 58	155	344
17	55 14 56	151	54 21 57	152	53 28 57	152	52 35 57	153	51 42 57	153	343
18	54 54 57	149	54 03 56	150	53 11 56	151	52 18 57	151	51 25 58	152	342
19	54 34 56	148	53 43 57	148	52 52 57	149	52 00 57	150	51 08 57	150	341
20	54 13+56	146	53 23+56	147	52 33+56	148	51 42+56	148	50 51+56	149	340
21	53 51 56	145	53 02 56	145	52 13 55	146	51 23 56	147	50 32 57	148	339
22	53 29 54	143	52 40 56	144	51 52 55	145	51 02 56	145	50 13 56	146	338
23	53 05 55	142	52 18 55	143	51 30 55	143	50 42 55	144	49 53 56	145	337
24	52 41 54	140	51 55 54	141	51 08 54	142	50 20 55	143	49 32 56	143	336
25	52 16+54	139	51 31+54	140	50 44+55	141	49 58+55	141	49 11+55	142	335
26	51 50 54	138	51 06 54	138	50 21 54	139	49 35 55	140	48 49 55	141	334
27	51 24 53	136	50 40 54	137	49 56 54	138	49 12 54	139	48 26 55	139	333
28	50 57 53	135	50 14 54	136	49 31 54	137	48 47 54	137	48 03 55	138	332
29	50 29 53	134	49 48 53	134	49 05 54	135	48 23 53	136	47 39 54	137	331
30	50 01+52	132	49 21+52	133	48 39+53	134	47 57+54	135	47 15+54	136	330
31	49 32 52	131	48 53 52	132	48 12 53	133	47 31 54	134	46 30 53	134	329
32	49 03 51	130	48 24 52	131	47 45 52	131	47 05 53	132	46 24 54	133	328
33	48 33 51	129	47 55 52	129	47 17 52	130	46 38 53	131	45 58 53	132	327
34	48 03 50	127	47 26 51	128	46 49 51	129	46 10 53	130	45 32 53	131	326
35	47 32+50	126	46 56+51	127	46 20+51	128	45 43+52	129	45 05+52	129	325
36	47 00 50	125	46 26 50	126	45 50 51	127	45 14 52	127	44 37 53	128	324
37	46 29 49	124	45 55 50	125	45 20 51	126	44 45 52	126	44 09 52	127	323
38	45 56 50	123	45 24 50	124	44 50 51	124	44 16 51	125	43 41 52	126	322
39	45 24 49	122	44 52 50	122	44 19 51	123	43 46 51	124	43 12 52	125	321
40	44 51+48	120	44 20+49	121	43 48+50	122	43 16+51	123	42 43+52	124	320
41	44 17 49	119	43 47 50	120	43 17 50	121	42 46 50	122	42 14 51	123	319
42	43 44 48	118	43 15 48	119	42 45 50	120	42 15 50	121	41 44 51	122	318
43	43 09 48	117	42 42 48	118	42 13 49	119	41 44 50	120	41 14 50	120	317
44	42 35 48	116	42 08 48	117	41 40 50	118	41 12 50	119	40 43 50	119	316
45	42 00+48	115	41 34+48	116	41 08+48	117	40 40+50	118	40 12+50	118	315

In North { For argument H.A. on the left, True Azimuth = 360° — Tabulated Azimuth. } See
Latitudes { For argument H.A. on the right, True Azimuth = Tabulated Azimuth. } p. 90.

Table 8.

21° DECLINATION **SAME** NAME AS LATITUDE **21°**

H.A.	Alt. (50°)		Az.	Alt. (51°)		Az.	Alt. (52°)		Az.	Alt. (53°)		Az.	Alt. (54°)		Az.	H.A.
		d			d			d			d			d		
0	61 00+60		180	60 00+60		180	59 00+60		180	58 01+59		180	57 01+60		180	360
1	61 00 60		178	60 00 60		178	59 00 60		178	58 00 60		178	57 00 60		178	359
2	60 58 60		176	59 58 60		176	58 58 60		177	57 58 60		176	56 58 60		177	358
3	60 55 59		174	59 55 60		174	58 55 60		175	57 56 59		175	56 56 59		175	357
4	60 50 60		172	59 51 59		173	58 51 60		173	57 52 59		173	56 52 60		173	356
5	60 44+60		170	59 45+60		171	58 46+60		171	57 47+59		171	56 47+60		171	355
6	60 37 60		169	59 38 60		169	58 40 59		170	57 41 59		169	56 42 59		170	354
7	60 29 59		167	59 31 59		167	58 32 59		167	57 34 59		168	56 35 59		168	353
8	60 19 59		165	59 22 59		165	58 23 60		166	57 25 60		166	56 27 59		166	352
9	60 09 58		163	59 11 59		163	58 14 59		164	57 16 59		164	56 18 59		165	351
10	59 57+58		161	59 00+59		162	58 03+59		162	57 06+59		163	56 09+58		163	350
11	59 44 58		159	58 48 58		160	57 51 59		160	56 55 58		161	55 58 59		161	349
12	59 30 57		158	58 34 58		158	57 38 59		159	56 42 59		159	55 46 59		160	348
13	59 14 58		156	58 20 57		156	57 24 58		157	56 29 58		158	55 33 59		158	347
14	58 58 57		154	58 04 57		155	57 10 57		155	56 15 58		156	55 20 58		157	346
15	58 41+56		152	57 47+57		153	56 54+57		154	56 00+57		154	55 05+58		155	345
16	58 22 57		151	57 30 56		151	56 37 57		152	55 44 57		153	54 50 58		153	344
17	58 03 56		149	57 11 56		150	56 19 57		151	55 27 57		151	54 34 57		152	343
18	57 42 56		147	56 52 56		148	56 01 56		149	55 09 57		150	54 17 57		150	342
19	57 21 55		146	56 31 56		147	55 41 56		147	54 50 57		148	53 59 57		149	341
20	56 59+55		144	56 10+55		145	55 21+55		146	54 31+56		147	53 41+56		147	340
21	56 36 54		143	55 48 55		143	55 00 55		144	54 11 55		145	53 21 56		146	339
22	56 12 54		141	55 25 55		142	54 38 55		143	53 50 55		144	53 01 56		144	338
23	55 48 53		140	55 02 54		140	54 15 55		141	53 28 55		142	52 40 56		143	337
24	55 22 53		138	54 37 54		139	53 52 54		140	53 05 55		141	52 19 55		142	336
25	54 56+53		137	54 12+53		138	53 27+54		139	52 42+55		139	51 56+55		140	335
26	54 29 53		135	53 46 53		136	53 03 53		137	52 18 54		138	51 34 54		139	334
27	54 02 52		134	53 20 52		135	52 37 53		136	51 54 54		137	51 10 54		137	333
28	53 34 51		132	52 53 52		133	52 11 53		134	51 29 53		135	50 46 54		136	332
29	53 05 51		131	52 25 52		132	51 44 53		133	51 03 53		134	50 21 54		135	331
30	52 36+50		130	51 57+51		131	51 17+52		132	50 37+53		133	49 56+53		134	330
31	52 06 50		129	51 28 51		130	50 49 52		130	50 10 52		131	49 30 53		132	329
32	51 35 50		127	50 59 50		128	50 21 51		129	49 43 52		130	49 04 52		131	328
33	51 04 50		126	50 29 50		127	49 52 51		128	49 15 52		129	48 37 52		130	327
34	50 33 49		125	49 58 50		126	49 23 50		127	48 47 51		128	48 10 52		129	326
35	50 01+49		124	49 27+50		125	48 53+50		126	48 18+51		126	47 42+51		127	325
36	49 29 48		122	48 56 49		123	48 23 50		124	47 48 51		125	47 13 52		126	324
37	48 56 48		121	48 24 49		122	47 52 50		123	47 19 50		124	46 45 51		125	323
38	48 23 48		120	47 52 49		121	47 21 49		122	46 49 50		123	46 16 51		124	322
39	47 49 48		119	47 20 48		120	46 49 50		121	46 18 50		122	45 46 51		123	321
40	47 15+48		118	46 47+48		119	46 17+49		120	45 47+50		121	45 16+51		122	320
41	46 41 47		117	46 14 47		118	45 45 49		119	45 16 50		120	44 46 50		120	319
42	46 06 47		116	45 40 48		117	45 13 48		118	44 44 50		118	44 16 49		119	318
43	45 32 46		115	45 06 48		116	44 40 48		117	44 13 49		117	43 45 49		118	317
44	44 56 47		114	44 32 47		115	44 07 48		115	43 40 49		116	43 13 50		117	316
45	44 21+46		113	43 57+47		114	43 33+48		114	43 08+48		115	42 42+49		116	315

In North { For argument H.A. on the left, True Azimuth = 360° − Tabulated Azimuth. }
Latitudes { For argument H.A. on the right, True Azimuth = Tabulated Azimuth. }

Table 9.

ACRUX   **SOUTH** LATITUDES   **2**

LAT.	50°		51°		52°		53°		54°		LAT.
H.A.	Alt.	Az.	Alt.	Az.	Alt.	Az.	Alt.	Az.	Alt.	Az.	H.A.
135	28 16+17	22	29 12+17	22	30 07+17	22	31 03+17	22	31 58+17	22	225
136	28 02 17	21	28 58 17	21	29 54 17	22	30 49 17	22	31 45 17	22	224
137	27 48 17	21	28 44 17	21	29 40 17	21	30 36 18	21	31 32 18	21	223
138	27 35 17	20	28 31 18	20	29 27 18	21	30 23 18	21	31 19 18	21	222
139	27 22 18	20	28 18 18	20	29 14 18	20	30 11 18	20	31 07 18	21	221
140	27 09+18	19	28 05+18	19	29 02+18	20	29 58+18	20	30 54+18	20	220
141	26 56 18	19	27 53 18	19	28 49 18	19	29 46 18	19	30 43 18	20	219
142	26 44 18	18	27 41 18	19	28 37 18	19	29 34 18	19	30 31 18	19	218
143	26 32 18	18	27 29 18	18	28 26 18	18	29 23 18	18	30 20 18	19	217
144	26 20 18	17	27 17 18	18	28 14 18	18	29 11 18	18	30 08 18	18	216
145	26 09+18	17	27 06+18	17	28 03+18	17	29 00+18	17	29 58+18	18	215
146	25 58 18	17	26 55 18	17	27 52 18	17	28 50 18	17	29 47 18	17	214
147	25 47 18	16	26 44 18	16	27 42 18	16	28 39 19	16	29 37 19	17	213
148	25 36 18	16	26 34 19	16	27 32 19	16	28 29 19	16	29 27 19	16	212
149	25 26 19	15	26 24 19	15	27 22 19	15	28 19 19	16	29 17 19	16	211
150	25 16+19	15	26 14+19	15	27 12+19	15	28 10+19	15	29 08+19	15	210
151	25 07 19	14	26 05 19	14	27 03 19	14	28 01 19	15	28 59 19	15	209
152	24 57 19	14	25 56 19	14	26 54 19	14	27 52 19	14	28 50 19	14	208
153	24 48 19	13	25 47 19	13	26 45 19	13	27 43 19	14	28 42 19	14	207
154	24 40 19	13	25 38 19	13	26 37 19	13	27 35 19	13	28 33 19	13	206
155	24 31+19	12	25 30+19	12	26 28+19	12	27 27+19	13	28 25+19	13	205
156	24 23 19	12	25 22 19	12	26 21 19	12	27 19 19	12	28 18 19	12	204
157	24 16 19	11	25 14 19	11	26 13 19	11	27 12 19	12	28 11 19	12	203
158	24 08 19	11	25 07 19	11	26 06 19	11	27 05 19	11	28 04 19	11	202
159	24 01 19	10	25 00 19	10	25 59 19	11	26 58 19	11	27 57 19	11	201
160	23 54+19	10	24 53+19	10	25 52+19	10	26 51+19	10	27 50+19	10	200
161	23 48 19	9	24 47 19	9	25 46 19	10	26 45 19	10	27 44 19	10	199
162	23 42 19	9	24 41 19	9	25 40 19	9	26 39 20	9	27 39 20	9	198
163	23 36 20	8	24 35 20	8	25 35 20	9	26 34 20	9	27 33 20	9	197
164	23 31 20	8	24 30 20	8	25 29 20	8	26 29 20	8	27 28 20	8	196
165	23 26+20	7	24 25+20	7	25 24+20	8	26 24+20	8	27 23+20	8	195
166	23 21 20	7	24 20 20	7	25 20 20	7	26 19 20	7	27 19 20	7	194
167	23 16 20	6	24 16 20	6	25 15 20	7	26 15 20	7	27 14 20	7	193
168	23 12 20	6	24 12 20	6	25 11 20	6	26 11 20	6	27 10 20	6	192
169	23 08 20	5	24 08 20	5	25 08 20	6	26 07 20	6	27 07 20	6	191
170	23 05+20	5	24 04+20	5	25 04+20	5	26 04+20	5	27 04+20	5	190
171	23 02 20	4	24 01 20	4	25 01 20	5	26 01 20	5	27 01 20	5	189
172	22 59 20	4	23 59 20	4	24 58 20	4	25 58 20	4	26 58 20	4	188
173	22 56 20	3	23 56 20	3	24 56 20	4	25 56 20	4	26 55 20	4	187
174	22 54 20	3	23 54 20	3	24 54 20	3	25 54 20	3	26 53 20	3	186
175	22 52+20	2	23 52+20	3	24 52+20	3	25 52+20	3	26 52+20	3	185
176	22 51 20	2	23 51 20	2	24 51 20	2	25 50 20	2	26 50 20	2	184
177	22 50 20	1	23 49 20	2	24 49 20	2	25 49 20	2	26 49 20	2	183
178	22 49 20	1	23 49 20	1	24 49 20	1	25 48 20	1	26 48 20	1	182
179	22 48 20	1	23 48 20	1	24 48 20	1	25 48 20	1	26 48 20	1	181
180	22 48+20	0	23 48+20	0	24 48+20	0	25 48+20	0	26 48+20	0	180

{ For argument H.A. on the left, True Azimuth = 180° + Tabulated Azimuth. }
{ For argument H.A. on the right, True Azimuth = 180° − Tabulated Azimuth. }
No correction for date is necessary until 1944.

Table 10.

VEGA NORTH *LATITUDES* **22**

LAT.	50°		51°		52°		53°		54°		LAT.
H.A.	Alt.	Az.	Alt.	Az.	Alt.	Az.	Alt.	Az.	Alt.	Az.	H.A.
°	° ′ ′	°	° ′ ′	°	° ′ ′	°	° ′ ′	°	° ′ ′	°	°
45	56 30 +2	92	56 27 +2	94	56 23 +2	95	56 16 +2	97	56 09 +2	98	315
46	55 52 2	91	55 50 2	93	55 46 2	94	55 41 2	96	55 34 2	97	314
47	55 13 2	91	55 12 2	92	55 09 2	93	55 05 2	95	54 59 2	96	313
48	54 35 2	90	54 34 2	91	54 32 2	93	54 29 2	94	54 24 2	95	312
49	53 56 2	89	53 56 2	90	53 55 2	92	53 53 2	93	53 49 2	95	311
50	53 17 +2	88	53 19 +2	90	53 18 +2	91	53 17 +2	92	53 13 +2	94	310
51	52 39 2	88	52 41 2	89	52 41 2	90	52 41 2	91	52 38 2	93	309
52	52 00 2	87	52 03 2	88	52 04 2	89	52 04 2	91	52 03 2	92	308
53	51 22 2	86	51 25 2	87	51 28 2	89	51 28 2	90	51 28 2	91	307
54	50 44 2	85	50 48 2	87	50 51 2	88	50 52 2	89	50 53 2	90	306
55	50 05 +2	85	50 10 +2	86	50 14 +2	87	50 16 +2	88	50 17 +2	89	305
56	49 27 2	84	49 32 2	85	49 37 2	86	49 40 2	88	49 42 2	89	304
57	48 48 2	83	48 55 2	84	49 00 2	86	49 04 2	87	49 07 2	88	303
58	48 10 2	83	48 17 2	84	48 23 2	85	48 28 2	86	48 32 2	87	302
59	47 32 2	82	47 40 2	83	47 46 2	84	47 52 2	85	47 56 2	86	301
60	46 54 +2	81	47 02 +2	82	47 10 +2	83	47 16 +2	85	47 21 +2	86	300
61	46 16 2	81	46 25 2	82	46 33 2	83	46 40 2	84	46 46 2	85	299
62	45 38 2	80	45 48 2	81	45 57 2	82	46 04 2	83	46 11 2	84	298
63	45 00 2	79	45 10 2	80	45 20 2	81	45 29 2	82	45 36 2	83	297
64	44 22 2	79	44 33 2	80	44 44 2	81	44 53 2	82	45 01 2	83	296
65	43 44 +2	78	43 56 +2	79	44 07 +2	80	44 17 +2	81	44 26 +2	82	295
66	43 07 2	77	43 19 2	78	43 31 2	79	43 42 2	80	43 51 2	81	294
67	42 29 2	77	42 42 2	78	42 55 2	79	43 06 2	80	43 16 2	80	293
68	41 52 2	76	42 05 2	77	42 18 2	78	42 31 2	79	42 42 2	80	292
69	41 14 2	76	41 29 2	77	41 42 2	77	41 55 2	78	42 07 2	79	291
70	40 37 +2	75	40 52 +2	76	41 06 +2	77	41 20 +2	77	41 33 +2	78	290
71	40 00 2	74	40 16 2	75	40 31 2	76	40 45 2	77	40 58 2	78	289
72	39 23 2	74	39 39 2	74	39 55 2	75	40 10 2	76	40 24 2	77	288
73	38 46 2	73	39 03 2	74	39 19 2	75	39 35 2	75	39 49 2	76	287
74	38 09 2	72	38 27 2	73	38 44 2	74	39 00 2	75	39 15 2	76	286
75	37 32 +2	72	37 51 +2	73	38 08 +2	73	38 25 +2	74	38 41 +2	75	285
76	36 56 2	71	37 15 2	72	37 33 2	73	37 50 2	73	38 07 2	74	284
77	36 19 2	71	36 39 2	71	36 58 2	72	37 16 2	73	37 33 2	73	283
78	35 43 2	70	36 03 2	71	36 23 2	71	36 41 2	72	37 00 2	73	282
79	35 07 2	69	35 28 2	70	35 48 2	71	36 07 2	71	36 26 2	72	281
80	34 31 +2	69	34 52 +2	69	35 13 +2	70	35 33 +2	71	35 53 +2	71	280
81	33 55 2	68	34 17 2	69	34 38 2	69	34 59 2	70	35 19 2	71	279
82	33 19 2	68	33 42 2	68	34 04 2	69	34 25 2	69	34 46 2	70	278
83	32 44 2	67	33 07 2	68	33 30 2	68	33 52 2	69	34 13 2	69	277
84	32 08 2	66	32 32 2	67	32 55 2	68	33 18 2	68	33 40 2	69	276
85	31 33 +2	66	31 58 +2	66	32 21 +2	67	32 45 +2	67	33 07 +2	68	275
86	30 58 2	65	31 23 2	66	31 47 2	66	32 11 2	67	32 35 2	67	274
87	30 23 2	65	30 49 2	65	31 14 2	66	31 38 2	66	32 02 2	67	273
88	29 49 2	64	30 15 2	64	30 40 2	65	31 05 2	66	31 30 2	66	272
89	29 14 2	63	29 41 2	64	30 07 2	64	30 33 2	65	30 58 2	65	271
90	28 40 +2	63	29 07 +2	63	29 34 +2	64	30 00 +2	64	30 26 +2	65	270

{ For argument H.A. on the left, True Azimuth = 360° − Tabulated Azimuth. }
{ For argument H.A. on the right, True Azimuth = Tabulated Azimuth. }
No correction for date is necessary until 1958.

Table 11.

XV.—CORRECTION TO TABULATED ALTITUDE FOR MINUTES OF DECLINATION

d	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	d
00	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	00
01	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	01
02	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	02
03	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	3	3	3	3	3	3	3	3	3	3	03
04	2	2	2	2	2	2	2	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	4	4	4	4	4	4	4	4	04
05	3	3	3	3	3	3	3	3	3	3	3	4	4	4	4	4	4	4	4	4	4	4	4	4	5	5	5	5	5	5	05
06	3	3	3	3	4	4	4	4	4	4	4	4	4	4	4	5	5	5	5	5	5	5	5	5	6	6	6	6	6	6	06
07	4	4	4	4	4	4	4	4	5	5	5	5	5	5	5	5	5	6	6	6	6	6	6	6	6	7	7	7	7	7	07
08	4	4	4	5	5	5	5	5	5	5	5	6	6	6	6	6	6	6	7	7	7	7	7	7	7	7	8	8	8	8	08
09	5	5	5	5	5	5	6	6	6	6	6	6	6	7	7	7	7	7	7	8	8	8	8	8	8	8	9	9	9	9	09
10	5	5	6	6	6	6	6	6	6	7	7	7	7	7	8	8	8	8	8	8	8	9	9	9	9	9	10	10	10	10	10
11	6	6	6	6	6	7	7	7	7	7	8	8	8	8	8	8	9	9	9	9	9	10	10	10	10	10	10	11	11	11	11
12	6	6	7	7	7	7	7	8	8	8	8	8	9	9	9	9	9	10	10	10	10	10	11	11	11	11	11	12	12	12	12
13	7	7	7	7	8	8	8	8	8	9	9	9	9	10	10	10	10	10	11	11	11	11	11	12	12	12	12	13	13	13	13
14	7	7	8	8	8	8	9	9	9	9	10	10	10	10	10	11	11	11	11	12	12	12	12	13	13	13	13	14	14	14	14
15	8	8	8	8	9	9	9	10	10	10	10	10	11	11	11	12	12	12	12	12	13	13	13	14	14	14	14	14	15	15	15
16	8	9	9	9	9	10	10	10	10	11	11	11	11	12	12	12	13	13	13	13	14	14	14	14	15	15	15	15	16	16	16
17	9	9	9	10	10	10	10	11	11	11	12	12	12	12	13	13	13	14	14	14	14	14	15	15	16	16	16	16	17	17	17
18	9	10	10	10	10	11	11	11	12	12	12	13	13	13	14	14	14	14	15	15	15	16	16	16	16	17	17	17	18	18	18
19	10	10	10	11	11	11	12	12	12	13	13	13	14	14	14	15	15	15	16	16	16	16	17	17	17	18	18	18	19	19	19
20	10	11	11	11	12	12	12	13	13	13	14	14	14	15	15	15	16	16	16	17	17	17	18	18	18	19	19	19	20	20	20
21	11	11	12	12	12	13	13	13	14	14	14	15	15	15	16	16	16	17	17	18	18	18	19	19	19	20	20	20	21	21	21
22	11	12	12	12	13	13	14	14	14	15	15	15	16	16	16	17	17	18	18	18	19	19	19	20	20	21	21	21	22	22	22
23	12	12	13	13	13	14	14	15	15	15	16	16	16	17	17	17	18	18	19	19	20	20	20	21	21	21	22	22	23	23	23
24	12	13	13	14	14	14	15	15	16	16	16	17	17	18	18	18	19	19	20	20	20	21	21	22	22	22	23	23	24	24	24
25	13	13	14	14	15	15	15	16	16	17	17	18	18	18	19	19	20	20	20	21	21	22	22	22	23	23	24	24	25	25	25
26	13	14	14	15	15	16	16	16	17	17	18	18	19	19	20	20	20	21	21	22	22	23	23	23	24	24	25	25	26	26	26
27	14	14	15	15	16	16	17	17	18	18	18	19	19	20	20	21	21	22	22	22	23	23	24	24	25	25	26	26	27	27	27
28	14	15	15	16	16	17	17	18	18	19	19	20	20	21	21	21	22	22	23	23	24	24	25	25	26	26	27	27	28	28	28
29	15	15	16	16	17	17	18	18	19	19	20	20	21	21	22	22	23	23	24	24	25	25	26	26	27	27	28	28	29	29	29
30	16	16	16	17	18	18	18	19	20	20	20	21	22	22	22	23	24	24	24	25	26	26	26	27	28	28	28	29	30	30	30
31	16	17	17	18	18	19	19	20	20	21	21	22	22	23	23	24	24	25	25	26	26	27	27	28	28	29	29	30	30	31	31
32	17	17	18	18	19	19	20	20	21	21	22	22	23	23	24	25	25	26	26	27	27	28	28	29	29	30	30	31	31	32	32
33	17	18	18	19	19	20	20	21	21	22	23	23	24	24	25	25	26	26	27	28	28	29	29	30	30	31	31	32	32	33	33
34	18	18	19	19	20	20	21	21	22	23	23	24	24	25	26	26	27	27	28	28	29	29	30	31	31	32	32	33	33	34	34
35	18	19	19	20	20	21	22	22	23	23	24	24	25	26	26	27	27	28	29	29	30	30	31	32	32	33	33	34	34	35	35
36	19	19	20	20	21	22	22	23	23	24	25	25	26	26	27	28	28	29	29	30	31	31	32	32	33	34	34	35	35	36	36
37	19	20	20	21	22	22	23	23	24	25	25	26	27	27	28	28	29	30	30	31	31	32	33	33	34	35	35	36	36	37	37
38	20	20	21	22	22	23	23	24	25	25	26	27	27	28	28	29	30	30	31	32	32	33	34	34	35	36	36	37	37	38	38
39	20	21	21	22	23	23	24	25	25	26	27	27	28	29	29	30	31	31	32	32	33	34	34	35	36	36	37	38	38	39	39
40	21	21	22	23	23	24	25	25	26	27	27	28	29	29	30	31	31	32	33	33	34	35	35	36	37	37	38	39	39	40	40
41	21	22	23	23	24	25	25	26	27	27	28	29	29	30	31	31	32	33	33	34	34	36	36	37	38	38	39	40	40	41	41
42	22	22	23	24	24	25	26	27	27	28	29	29	30	31	32	32	33	34	34	35	36	36	37	38	38	39	40	41	41	42	42
43	22	23	24	24	25	26	27	27	28	29	29	30	31	32	32	33	34	34	35	36	37	37	38	39	39	40	41	42	42	43	43
44	23	23	24	25	26	26	27	28	29	29	30	31	32	32	33	34	34	35	36	37	37	38	39	40	40	41	42	43	43	44	44
45	23	24	25	26	26	27	28	28	29	30	31	32	32	33	34	34	35	36	37	38	38	39	40	40	41	42	43	44	44	45	45
46	24	25	25	26	27	28	28	29	30	31	31	32	33	34	34	35	36	36	38	39	40	41	42	42	43	44	44	45	45	46	46
47	24	25	26	27	27	28	29	30	31	31	32	33	34	34	35	36	37	38	38	39	40	41	42	42	43	44	45	45	46	47	47
48	25	26	26	27	28	29	30	30	31	32	33	34	34	35	36	37	38	38	39	40	41	42	42	43	44	45	46	46	47	48	48
49	25	26	27	28	29	29	30	31	32	33	33	34	35	36	37	38	38	39	40	41	42	42	43	44	44	45	46	47	48	49	49
50	26	27	28	28	29	30	31	32	32	33	34	35	36	37	38	38	39	40	41	42	42	43	44	45	46	47	48	48	49	50	50
51	26	27	28	29	30	31	31	32	33	34	35	36	37	37	38	39	40	41	42	42	43	44	45	46	47	48	48	49	50	51	51
52	27	28	29	29	30	31	32	33	34	35	36	36	37	38	39	40	41	42	42	43	44	45	46	47	48	49	49	50	51	52	52
53	27	28	29	30	31	32	33	34	34	35	36	37	38	39	40	41	42	42	43	44	45	46	47	48	49	49	50	51	52	53	53
54	28	29	30	31	32	32	33	34	35	36	37	38	39	40	40	41	42	43	43	44	45	46	47	48	49	50	51	52	53	54	54
55	28	29	30	31	32	33	34	35	36	37	38	38	39	40	41	42	43	44	45	46	47	48	49	50	50	51	52	53	54	55	55
56	29	30	31	32	33	34	35	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	49	50	51	52	53	54	55	56	56
57	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	52	53	54	55	56	57	57
58	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	58
59	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	59

Table 12.

ASTRONOMICAL AIR NAVIGATION

Z CORRECTION TO BUBBLE SEXTANT READING IN FLIGHT

Z TABLE (i)

T.A.S M.P.H.	Latitude														Wander deg. per min														T.A.S KNOTS
	0°	10°	20°	30°	40°	50°	60°	70°	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9					
100	0	0	1	1	1	2	2	2	0	0	1	1	1	2	3	3	4	4	87
150	0	0	1	2	2	3	3	3	0	1	1	2	3	3	4	5	5	5	130
200	0	1	2	2	3	3	4	4	0	1	2	3	4	5	5	6	7	8	174
250	0	1	2	3	4	4	5	5	0	1	2	3	5	6	7	8	9	10	217
300	0	1	2	3	4	5	6	6	0	1	3	4	5	7	8	10	11	12	261
350	0	1	3	4	5	6	7	7	0	2	3	5	6	8	10	11	13	14	305
400	0	1	3	5	6	7	8	9	0	2	4	5	7	9	11	13	15	16	348
SIGN	**N**	**+**			**S**	**−**			**PORT**	**+**			**STARBOARD**	**−**					**SIGN**

Combine the values from Table (i) and enter Table (ii)

Z TABLE (ii)

Relative bearing PORT	Combined value from Z Table (i)														Relative bearing STARB.
	0′	2′	4′	6′	8′	10′	12′	14′	16′	18′	20′	22′	24′	26′ · 28′	
360	0	0	0	0	0	0	0	0	0	0	0	0	0	0 0	0
350	0	0	1	1	1	2	2	2	3	3	3	4	4	5 5	10
340	0	1	1	2	3	3	4	5	5	6	7	8	8	9 10	20
330	0	1	2	3	4	5	6	7	8	9	10	11	12	13 14	30
315	0	1	3	4	6	7	8	10	11	13	14	16	17	18 20	45
300	0	2	3	5	7	9	10	12	14	16	17	19	21	23 24	60
270	0	2	4	6	8	10	12	14	16	18	20	22	24	26 28	90
240	0	2	3	5	7	9	10	12	14	16	17	19	21	23 24	120
225	0	1	3	4	6	7	8	10	11	13	14	16	17	18 20	135
210	0	1	2	3	4	5	6	7	8	9	10	11	12	13 14	150
200	0	1	1	2	3	3	4	5	5	6	7	8	8	9 10	160
190	0	0	1	1	1	2	2	2	3	3	3	4	4	5 5	170
180	0	0	0	0	0	0	0	0	0	0	0	0	0	0 0	180

SIGN FOR Z CORRECTION

If value from Table (i) is :—	Relative bearing		
	PORT (left argument)	**STARBOARD** (right argument)	
+	**SUBTRACT**	**ADD**	Correction from Table (ii) to observed altitude
−	**ADD**	**SUBTRACT**	

In Table (i) the rate of Gyro Precession is defined by the wander of the aircraft from its compass course, when flying by the directional gyro or by automatic pilot ; the rate is measured by flying on a steady course for about 20 minutes ; during this period the compass course will gradually change—the change of compass reading in degrees divided by the time elapsed in minutes will give the required rate (allowance must be made for change of magnetic variation). The rate should thus be measured on several flights to give a good average value to be recorded for use.   If the pilot is flying on a gyro magnetic compass there will be NO Gyro Precession (i.e. the Wander is 0·0 deg. per min.).

For explanation of this table, and illustrations of its use in practice see facing page.

Table 13.

Z CORRECTION ; EXPLANATION AND EXAMPLE

Explanation. Table (i) gives the movement of the bubble from the true vertical, in minutes of arc, due to the effects of Coriolis acceleration and of Gyro Precession ; the total movement of the bubble is obtained by taking the combined value from **Z** Table (i).

The correction to be applied to the observed altitude depends upon the relative bearing of the observed body—the full correction is applied for beam observations, while the correction is zero for observations ahead or astern. **Z** Table (ii) gives the actual corrections, in minutes of arc, and the signs with which they are to be applied, for all movements and relative bearings.

	Example only	
T.A.S 270 m.p.h.		
Lat. N. 56°		
Wander 0·75 (STARB.)		
Combined value Table (i) −4′		

Relative bearing PORT	Combined value from Table (i) −4′	Relative bearing STARB.
360	0	0
350	1	10
340	1	20
330	2	30
315	3	45
300	3	60
270	4	90
240	3	120
225	3	135
210	2	150
200	1	160
190	1	170
180	0	180
ADD	to or from observed altitude	SUB-TRACT

(Column 2 marked "Example")

Example

T.A.S. 270 m.p.h. (235 kts.) ; Lat. N. 56°, wander to starboard 0·75 deg./min., relative bearing 230° (port). From Table (i) the values are +5′ (due to Coriolis) and −9′ (due to Gyro Precession) = −4′ (combined value).

From Table (ii) the Z correction is seen to be 3′, which is to be *added* (value from Table (i) −, relative bearing port) to the observed altitude.

In a particular aircraft, the navigator will know by experience his mean T.A.S. and wander, as well as his operational latitude : a single column of Table (ii) can thus be specified and copied in a convenient place. This is shown on the left for the above example, while a blank table is provided on the right for operational use.

The signs with which the correction is to be applied should be filled in according to the rules given for the signs

Aircraft No.		
T.A.S.		
Lat.		
Wander		
Combined value Table (i)		

Relative bearing PORT	Combined value from Table (i)	Relative bearing STARB.
360		0
350		10
340		20
330		30
315		45
300		60
270		90
240		120
225		135
210		150
200		160
190		170
180		180
	to or from observed altitude	

ADJUSTMENT TO POLE STAR TABLE

The table alongside gives the adjustment to be applied to the Pole Star Table if special accuracy is required. It should only be used for low altitudes and heights, unless accurate observations are available.

Height in Feet	Observed Altitude						
	10°	15°	20°	30°	45°	60°	75°
0	−4	−3	−2	−1	0	0	+1
5,000	−4	−2	−1	0	0	+1	+1
10,000	−3	−2	−1	0	0	+1	+1
15,000	−2	−1	−1	0	0	+1	+1
20,000	−2	−1	0	0	0	+1	+1
25,000	−1	−1	0	0	+1	+1	+1
30,000	−1	0	0	0	+1	+1	+1
35,000	−1	0	0	0	+1	+1	+1
40,000	0	0	0	+1	+1	+1	+1

Table 13 (*contd.*).

EAST SETTING LONGITUDES

				Local night and hours of A.M.T.							Corresponding G.M.T.
M /Tu. 31–1	Tu./W. 1–2	W /Th 2–3	Th /F 3–4	F./S 4–5	S /☾ 5–6	☾ /M 6–7	M./Tu 7–8	Tu /W 8–9	W /Th 9–10	Th /F. 10–11	
11ʰ	11ʰ	11ʰ	11ʰ	11ʰ	11ʰ	11ʰ	11ʰ	11ʰ	11ʰ	12ʰ	
E5 26	E4 27	E3 28	E2 29	E1 30	E0 30	W0 29	W1 28	W2 27	W3 26	E10 37	24
12 57	11 58	10 59	10 00	9 01	8 02	E7 02	E6 03	E5 04	E4 05	18 08	23 30
20 29	19 29	18 30	17 31	16 32	15 33	14 34	13 35	12 35	11 36	25 40	23
35 31	34 32	33 33	32 34	31 34	30 35	29 36	28 37	27 38	26 39	40 42	22
50 33	49 34	48 35	47 36	46 37	45 38	44 39	43 39	42 40	41 41	55 45	21
65 36	64 37	63 38	62 39	61 39	60 40	59 41	58 42	57 43	56 44	70 47	20
80 38	79 39	78 40	77 41	76 42	75 43	74 44	73 44	72 45	71 46	85 49	19
95 41	94 42	93 43	92 43	91 44	90 45	89 46	88 47	87 48	86 49	100 52	18
110 43	109 44	108 45	107 46	106 47	105 48	104 48	103 49	102 50	101 51	115 54	17
125 46	124 47	123 48	122 48	121 49	120 50	119 51	118 52	117 53	116 54	130 57	16
140 48	139 49	138 50	137 51	136 52	135 53	134 53	133 54	132 55	131 56	145 59	15
155 51	154 52	153 52	152 53	151 54	150 55	149 56	148 57	147 58	146 58	161 02	14
170 53	169 54	168 55	167 56	166 57	165 57	164 58	163 59	163 00	162 01	176 04	13
…	…						179 02	178 03	177 03	..	12

F./S 11–12	S /☾ 12–13	☾ /M 13–14	M /Tu 14–15	Tu /W 15–16	W /Th. 16–17	Th /F 17–18	F /S 18–19	S /☾ 19–20	☾ /M 20–21	M /Tu 21–22	Corresponding G.M.T.
12ʰ	12ʰ	12ʰ	12ʰ	12ʰ	12ʰ	12ʰ	12ʰ	12ʰ	12ʰ	12ʰ	
E9 38	E8 39	E7 40	E6 41	E5 41	E4 42	E3 43	E2 44	E1 45	E0 46	W0 13	24
17 09	16 10	15 11	14 12	13 13	12 14	11 14	10 15	9 16	8 17	L7 18	23 30
24 40	23 41	22 42	21 43	20 44	19 45	18 46	17 47	16 47	15 48	14 49	23
39 43	38 44	37 45	36 46	35 46	34 47	33 48	32 49	31 50	30 51	29 52	22
54 45	53 46	52 47	51 48	50 49	49 50	48 51	47 51	46 52	45 53	44 54	21
69 48	68 49	67 50	66 50	65 51	64 52	63 53	62 54	61 55	60 56	59 56	20
84 50	83 51	82 52	81 53	80 54	79 55	78 55	77 56	76 57	75 58	74 59	19
99 53	98 54	97 55	96 55	95 56	94 57	93 58	92 59	92 00	91 01	90 01	18
114 55	113 56	112 57	111 58	110 59	110 00	109 00	108 01	107 02	106 03	105 04	17
129 58	128 59	127 59	127 00	126 01	125 02	124 03	123 04	122 05	121 05	120 06	16
145 00	144 01	143 02	142 03	141 04	140 04	139 05	138 06	137 07	136 08	135 09	15
160 03	159 04	158 04	157 05	156 06	155 07	154 08	153 09	152 10	151 10	150 11	14
175 05	174 06	173 07	172 08	171 09	170 09	169 10	168 11	167 12	166 13	165 14	13
..											12

Tu./W 22–23	W /Th. 23–24	Th /F 24–25	F /S 25–26	S /☾ 26–27	☾ /M 27–28	M /Tu 28–29	Tu /W 29–30	W /Th 30–1	Th /F 1–2	F /S 2–3	Corresponding G.M.T.
12ʰ	12ʰ	12ʰ	13ʰ	13ʰ	13ʰ	13ʰ	13ʰ	13ʰ	13ʰ	13ʰ	
W1 13	W2 12	W3 11	E10 53	E9 53	E8 54	E7 55	E6 56	E5 57	E4 58	E3 59	24
E6 19	E5 20	E4 20	18 24	17 25	16 25	15 26	14 27	13 28	12 29	11 30	23 30
13 50	12 51	11 52	25 55	24 56	23 57	22 58	21 58	20 59	20 00	19 01	23
28 52	27 53	26 54	40 57	39 58	38 59	38 00	37 01	36 02	35 03	34 04	22
43 55	42 56	41 57	56 00	55 01	54 02	53 03	52 03	51 04	50 05	49 06	21
58 57	57 58	56 59	71 02	70 03	69 04	68 05	67 06	66 07	65 08	64 08	20
74 00	73 01	72 02	86 05	85 06	84 07	83 07	82 08	81 09	80 10	79 11	19
89 02	88 03	87 04	101 07	100 08	99 09	98 10	97 11	96 12	95 12	94 13	18
104 05	103 06	102 06	116 10	115 11	114 12	113 12	112 13	111 14	110 15	109 16	17
119 07	118 08	117 09	131 12	130 13	129 14	128 15	127 16	126 17	125 17	124 18	16
134 10	133 11	132 11	146 15	145 16	144 16	143 17	142 18	141 19	140 20	139 21	15
149 12	148 13	147 14	161 17	160 18	159 19	158 20	157 21	156 21	155 22	154 23	14
164 15	163 15	162 16	176 20	175 21	174 21	173 22	172 23	171 24	170 25	169 24	13
179 17	178 18	177 19	…	..							12

On this page the corresponding G.M.T. is on the first (emphasised) of the two Greenwich Dates.

Table 14.

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